THE GEM TOURMALINE FIELD

OF SOUTHERN CALIFORNIA

BY WALDEMAR T. SCHALLER

United States Geological Survey

Unpublished manuscript circa 1925 [1]

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[1] This document, parts of which existed in 1905, after extensive internal USGS reviews was eventually created and prepared for publication as U. S. G. S. Professional Paper 92 which would have had a 1925-26 publication date. For various reasons this never happened and the document since then has had a long and convoluted history up to 2023 which is described as best as possible in the appendix attached at the end of this book.

Plate I. Tourmaline with quartz, albite, and hatchettolite, Himalaya Mine, Mesa Grande [This specimen which was still at the Smithsonian Institution in 2008, is attributed to a pegmatite in the Pala District, possibly the Tourmaline Queen mine and not the Himalaya mine as labeled by Schaller.]

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Preface

By F.W. Clarke

In southern California there is a remarkable region which has already produced gems to the value of about $3,700,000. These gems, the lithia tourmalines, are associated with lepidolite, which is also of commercial value, and with the peculiar foliated variety of albite known as cleavelandite. These minerals are associated at many localities throughout the world. In Maine, Brazil, Elba, Moravia, Siberia, and Madagascar the same minerals are found under strikingly similar conditions, showing that identical chemical reactions have led to identical results. With these typical minerals, many others are found, different minerals occurring at different places. Kunzite is characteristic of the California field; the beautiful rose beryl occurs in its finest development in Madagascar; and ordinary beryl is found at probably all the localities.

In the United States the famous locality at Paris, Main, long monopolized attention and furnished some of the finest gem tourmalines known, but it is now surpassed, at least in magnitude, by the California region, which is the subject of monographic paper. The gem and lithia mines of the district are here studied with great thoroughness, and the individual minerals found are described geologically, chemically, and crystallographically. The localities are also compared with those of other countries, and the similarities mentioned above and clearly shown. The analytical data are remarkably full, and the series of analyses of the tourmalines and lepidolites are very complete. Several new minerals have been discovered in especially a group of phosphates derived by alteration from lithiophilite, and new light is shed upon the so-called bismuth ocher, which differs widely from the supposed species described in the literature of mineralogy.

In short, this memoir is the most exhaustive study of the lithium-bearing pegmatites that has yet been made and reflects great credit upon its author.

THE GEM TOURMALINE FIELD OF SOUTHERN CALIFORNIA

BY WALDEMAR T. SCHALLER

Part I. Introduction

Location

The gem tourmaline field of southern California, lying in large part in San Diego County, but also extending northward into Riverside County, has attracted much attention during the last decade for its wonderful deposits of gem minerals. Several of these deposits have been so valuable that extensive work has been done on them, and they have yielded a magnificent suite of gem minerals which in quantity and beauty are hardly surpassed by any other like suite in the world. All the mines but one have been exploited for their gem minerals, of which tourmaline and spodumene are the most valuable. One mine was developed for lepidolite and amblygonite to be used in the manufacture of lithium salts. Lithium is an essential constituent of all these minerals, and the deposits described in this report are therefore collectively referred to as deposits of lithium minerals. The value of the gem tourmalines produced is greater than that of all the other minerals combined, so that the area may justly be described as a gem tourmaline field.

A rectangular area extending from 116° 30' to 117° 15' west longitude and from 33° 00' to 33° 45' north latitude includes all the known deposits of lithium minerals in this region. This area, represented by the shaded region in figure 1, extends about 54 miles from north to south and about 44 miles from each to west and covers about 2,400 square miles. The actual extreme distance, north to south, between the deposits is, however only about 40 miles and the distance from east to west is about 30 miles, so that an area of 1,200 square miles would include all the known deposits. E.S. Larsen, of the Geological Survey, noticed[2] what was apparently lepidolite near Corona, Riverside County, about 36 miles northwest of Temecula, and Mr. C. R. Orcutt has reported[3] lepidolite and gem tourmaline in the Santa Rosa Mountains in Lower California, 20 miles below the Mexican boundary. When these reported occurrences have been verified, the limits of the gem tourmaline field will have to be extended. Additional field work may also show that the lithium minerals occur in a larger area than is here given. All known occurrences of lithium minerals are shown on topographic maps published by the U.S. Geological Survey--the southern half of the San Jacinto sheet, the entire Ramona sheet, and the eastern half of the San Luis Rey sheet.[4]

[2]Personal communication.

[3] See bibliography for reference

[4] These sheets are printed in three colors-the cultural features such as roads, railroads, cities, and towns, as well as all lettering, are in black: the water features, such as lakes and rivers are in blue; and the contour lines showing altitude are in brown. These maps may be purchased (for 10 cents a sheet, post paid) from the Director, United States Geological Survey, Washington, D.C., from whom may also be obtained free an index map of the State which shows what maps of the State are available and also gives a list of the local agents, who generally keep in stock maps of areas in their vicinity.

Figure 1 Index map of California, showing position of gem tourmaline field (shaded areas).

The lithium minerals lie wholly in the area of post-Cambrian intrusive rocks and nearly at its northern end.

The extreme southern part of California, comprising San Diego County and Imperial County, possesses three very marked physiographic features, which have been described by Fairbanks[5] as the desert or eastern part, the mountainous or central part, and the coastal mesa or western part. The tourmaline field lies on the western slope of the central or mountainous part formed by the Peninsula Range, which extends from the junction of the Sierra Nevada and the Coast Range southward into Lower California.

The localities in this field where lithium minerals have been mined are shown in figure 2. Mining has been active only at Pala and at Mesa Grande. At the other places mining for gems has been carried on when the conditions were favorable but the work has been done in a desultory way.

Figure 2 General geology and localities of the gem tourmaline field of southern California.

The map includes that part of California lying south and west of the gem tourmaline field in order that the geographic position of the field may be the more readily recognized. The field is in a rough mountainous region which varies considerably in attitude and which contains many geographic features to which no widely known geographic names have been applied. Its lowest part, the part nearest the Pacific Ocean, is only a few feet above sea level. Aguanga Mountain (the southern part of Smith's Mountain), which is less than 40 miles east of the coast, is 6,000 feet high and Thomas Mountain, in the northeastern part of the field, is nearly 7,000 feet high. Short and high mountain ranges be in different parts of the field, and between them are many broad valleys, which might prove fertile if supplied with more water.

The country is a semi-desert, through not level. The high mesas that face the ocean, such as Mesa Grande, receive sufficient moisture to produce abundant timber but in the eastern part of the field and in an area in the central part water is scarce and the vegetation is that of a desert. Cacti and yucca abound, and though timber suitable for use in mining is found at several places (Mesa Grande, Ramona), it is scarce at others (as at Pala). There are enough roads to enable the traveler to reach any point in the region which, however is sparsely settled. So that he may not find suitable accommodations.

The physiography of the country presents many features of more than passing interest. The large valleys, now filled (according to Fairbanks) with Quaternary deposits, and the deep valleys, apparently cut by stream erosion, show that lakes and rivers, must once have existed in the region, and the deposits of other sedimentary rocks give evidence that the seacoast has u n d e r g o n e many . oscillations.

The following paragraphs contain brief explanations of the names of the localities referred to in this report or shown in figure 2. The names have been arranged alphabetically for convenience of reference.

Aguanga Mountain, the highest portion of Smith's Mountain, forms its southern

[5] References are given in the bibliography.

end.

Banner, best known on account of its gold mines, is situated near the center of San Diego County. The occurrence of lepidolite here represents the extreme southeastern limit of the gem tourmaline field.

Bonsall, consisting of a store, post office, and a few scattered houses, is midway between Pala and Oceanside. There are several prospects here, among them the axinite locality in Moosa Canyon.

Coahuila is a name applied to the region comprising the northeastern part of the tourmaline field, in Riverside County. The region is not readily accessible and the few settlements in it are very scattered. The term Coahuila, by general usage, includes the Coahuila and Terwilliger valleys, Coahuila Mountain on the northwest, and Thomas Mountain on the northeast. Red Mountain lies between Coahuila and Hemet. The White Cap (gem tourmaline) and Fano mines (gem spodumene and tourmaline reported) are on Coahuila Mountain; the Hamilton mine (gem tourmaline) is on Thomas Mountain; the Anita mine (gem tourmaline) is on Thomas Mountain; the Anita mine (gem tourmaline) lies just west of Red Mountain.

Hiriart Hill is the easternmost of the three gem-bearing hills northeast of Pala. On it are situated, the Katerina, Naylor-Vanderberg, Hiriart, Sempe, and San Pedro mines and several other prospects.

Mesa Grande is a prosperous settlement, situated on a high mesa, and contains numerous rich ranches and farms. The country is of much value agriculturally as well as in its relation to gem mining. It is the terminus of the stage line from Ramona, and an automobile stage service from San Diego to Warner's Springs passes through it. The mines, about 4 miles northwest of the Mesa Grande store and post office are near the summit of a small ridge which reaches an altitude of about 4,000 feet. Mesa Grande has become justly famous for its wonderful tourmalines.

Moosa Canyon is the name given to a small canyon lying a few miles southeast of Bonsall, in which a deposit of axinite has been exploited for gem stones.

Oak Grove is a small settlement on the eastern side of Aguanga Mountain and lies between Mesa Grande and Coahuila. There is no store here and the nearest post office is at Aguanga, in Riverside County. The stage from Temecula to Warner's Springs passes through Oak Gove. Three gem tourmaline prospects, known as the Simmons', the Naylor, and the Dyche claims, are near Oak Grove.

Pala is an Indian settlement, with agent's office and a school, the Warner's Ranch Indians having been transferred here in 1904. Before that time it was a small settlement consisting of only a few houses. The place is reached in a day's journey from San Diego City. The train may be taken as far as Oceanside, on the Pacific Ocean, a station of the Santa Fe railway between Los Angeles and San Diego City; here a stage line goes to Pala about 25 miles inland. A branch railroad extends inland from Oceanside to Fallbrook, from which place Pala may be reached by a 17-mile road. A branch railroad from Riverside also goes as far south as Temecula, which Pala may conveniently be reached by a road about 12 miles long. The name Pala includes the surrounding country for several miles, especially toward the northeast, where, from 2 to 4 miles distant, are three hills in which the mineral deposits are found. The important mines here are the Stewart, Tourmaline King, Tourmaline Queen, Pala Chief, Katerina, and Naylor-Vanderberg.

Pala Chief Hill is the central one of the group of three hills lying northeast of Pala. The Pala Chief mine is on its western side, just below the summit.

The Peninsular range is the chain of mountains extending southward from southern California into Lower California.

Ramona is a prosperous settlement of several hundred people and is the

commercial center for an extensive agricultural region. It is a stage station on the road to Mesa Grande and to Julian. The mines are about 4 miles each of the town and close to the stage road from Ramona to Julian. The chief mines are the Little Three, Surprise, A.B.C., and Reliance. Lithium minerals are not very abundant here and topaz and garnet have largely been the incentive for mining.

Red Mountain, see Coahuila.

Rincon is a name used fro the region lying about midway between Pala and Mesa Grande. A store and post office and few scattered settlements form the community. The Victor mine has produced spodumene (kunzite) and tourmaline and the Mack mine has yielded some fine blue and green beryl.

Smith's Mountain is the local name for the mountain range northeast of Pala and extending into Riverside County. It include Augus Tibia Mountains and Aguanga Mountain.

Stewart Hill is the westernmost of the three hills lying northeast of Pala. It has been called Pala Mountain, but that name designates the mountain southeast of Pala, as shown on the topographic maps of the U.S. Geological Survey. The Stewart, Tourmaline Queen, and Tourmaline King mines are on Stewart Hill.

Temecula, in Riverside County, is the southern terminus of the railroad from Riverside and is a convenient point from which to enter the tourmaline field by way of Pala.

Thomas Mountain, see Coahuila.

Warner's Springs, of Warner's ranch, are much frequented. The Indians that are now at Pala formerly lived here.

Historical Development

The mining of gem minerals in southern California is a very recent industry. A historical review of the discovery and opening up of the different deposits is given by Kunz[6] .According to him the first gem tourmalines were found in Riverside County in 1872, but the little work done was soon abandoned. The deposit of lepidolite at Pala was first worked about 1890, although the ore was not regularly mined as a source of lithium compounds until 1899. The famous tourmaline mines at Mesa Grande were opened in 1898 and were large producers up to 1910. Spodumene of gem value was discovered at Pala in 1902, and a year later a second deposit was found. The exploration extended northward into Riverside County, where several new deposits were found. During this time several other localities were producing gem tourmalines, and it may be said that the active mining for these gems in southern California dates from the beginning of the twentieth century. Although the most productive mines have now been worked for more than 10 years, the indications in the country adjacent to the tourmaline area are such that further findings of valuable deposits of these gem minerals may confidently be expected.

It was at first a favorite practice to hunt in small gullies for gem tourmalines and by following up these gullies, in which float tourmalines were found, to locate the parent rock usually near the top of a hill. Various minerals such as smoky or colorless quartz in well developed crystals were considered as good evidence of the presence of gem tourmalines. These minerals represent the non-altering residuum of the original matrix of the gem tourmalines.

The discovery of the lepidolite deposit at what is now the Stewart Mine, at Pala,

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[6] Bullletin 37 California State Mining Bureau 1905

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is said to have been made by an Indian deer hunter, who brought specimens of the rock to Pala.[7] Mr. Henry Magee, an old prospector, located the deposit as a quicksilver mine, mistaking the rubellite for cinnabar. Finding, however, no quicksilver, he neglected the claim, which was relocated by Mr. Alvarado as a marble quarry at least twenty years ago. The claim located by Mr. Magee and relocated by Mr. Alvarado is what is known locally as "The Forty", being the claim of 40 acres just southwest of the claim on which the Stewart mine is located. About 15 years ago a chemist visited the property and found that the lepidolite was valuable as a source of lithia. The claim was then resurveyed, and the main ore body was found to be off the claim. The adjoining claim containing the lepidolite was then located by other parties and is now known as the Stewart mine. The search for other additional deposits of lepidolite caused numerous other prospects in the vicinity to be opened and in several of them tourmaline, spodumene, and beryl of gem value were found. The years 1902, 1903, and 1904 saw the greatest amount of development work in the region around Pala.

It is reported that the Indians have long known of the presence of colored crystals of tourmaline at Mesa Grande and that some have even been found in Indian graves, which suggests that these colored tourmaline crystals may have been known and valued for a long time.[8] These crystals occurred at the top of a ridge and erosion had disintegrated the rock and exposed the tourmalines. Numerous crystals, blue, green, or red had been picked up by Indian children and cowboys, but the value of the crystals was not realized until1898, when actually prospecting was begun at Mesa Grande.

The development of the mines in which either lithium ore or gem minerals were found in abundance has, in general, progressed rapidly. The greatest development is in the mines at Mesa Grande where both the Himalaya mine and the San Diego mine have many hundreds of feet of tunnels and drifts. The extent to which these two mines have been developed is shown in figures 27, 29, and p. and p.

The Stewart mine, at Pala has also been developed by a system of tunnels, (figure 18, p.) so that the relations of the different mineral components of the deposit can be clearly followed. The Anita mine, in Riverside County, has also been exploited by a system of tunnels (figure 31p.) in search of gem-bearing pockets. The remaining mines have generally been developed by open cuts, though in many of them prospecting tunnels have been driven for short distances into the deposits.

Lack of funds and especially, needless litigation have delayed the working of many of these mines. Wherever possible, development is being rapidly pushed forward and gives every indication of yielding much material of interest and value.

Production and Value

The following figures showing the production of gems have been compiled largely from the reports on precious stones published annually by the USGS in Mineral Resources of the US. These figures were compiled by G.F. Kunz until 1907 and since then by D.B. Sterrett. The figures whenever possible have been verified by the production of the field. The weights given refer to rough gem material as produced from the mine.

The second table shows the value of all the gem material mined, estimated as rough material and as cut stones. I am greatly indebted to Mr. D.B. Sterrett for valuable help in preparing these tables.

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[7] Sickler, F.M., Kansas City Jeweller and Optician, May, 1904.

[8] Kunz, G.P. Gems, jewelers' materials, and ornamental stones of California: California State Mining Bureau. Bulletin 37, p. 23, 1905.

Estimated production of gems from gem tourmaline field of southern California, 1901-1912. The figures obtained from various sources as to the quantity of lithium ore produced from this region are greatly at variance and all seem too high. All the marketed supply of lithium ore has been produced from the Stewart mine at Pala.

In the year 1891 about 30 tons of lepidolite were taken out and shipped to the World's Fair in Chicago where the beauty of the specimens (Plate) excited universal admiration. The characteristic form and the association of the pink tourmaline with the nearly white lepidolite caused these specimens to become well known all over the world. No further ore was mined until 1899 when 30 tons were shipped to Germany, and in 1900 an additional 30 tons were sent to New York. Both of these shipments were used in trying processes for the extraction of the lithium contained in the lepidolite.

During the following years, up to 1905, small quantities of lepidolite were taken out, the largest output recorded being in 1904 when about 700 tons were mined. In 1904 and 1905, a large quantity of amblygonite was mined. The aggregate of the material carried away as specimens by visitors must be considerable. Owing to the development of a large body of amblygonite in South Dakota in 1907 and 1908, the price of lithium carbonate fell from $2 or $2.50 a pound to 50 cents a pound or less[9] and the production of lithium ore from the California field was reduced to practically nothing.

Estimates of the total quantity of lepidolite ore, mined and shipped and suitable for extraction of lithium, range between 1,000 and 2,000 short tons. To this production is to be added about 1,000 short tons of amblygonite.

Sketch of work done[10]

My first visit to the field was made in the summer of 1903, when as a graduate student in the University of California [Berkeley], I spent several weeks at most of the localities. On my return to the university, the study of the collected material and a description of the lilac–colored spodumene, then newly found and soon afterward named kunzite, was published, also in 1903, as a bulletin[11] of the Department of Geology of the University of California. Soon afterward I became a member of the United States Geological Survey where the study of the subject was continued. In the summer of 1904, a longer period was spent in the California field and a visit was also made to the spodumene locality in South Dakota and to most of the gem localities in New England. A very brief trip was made to some of the Californian localities in 1905; since then the study of the minerals collected was followed as time became available, but the press of other work did not permit much progress. In December 1908, a disastrous fire destroyed much of the material that had been accumulated, and in the spring of 1909, I again visited the California localities, collecting material and noting the progress since 1906. The spring and summer of 1912 were spent in Europe, where the study of the material was continued especially at the Universities of Munich and Heidelberg. A summary of the results obtained on the tourmaline group were submitted and accepted as a doctorate dissertation by the University of Munich. Many other European museums and

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[9] Hess, Frank, L., Lithium in 1909: US Geological Survey Mineral Resources, 1909, pt. 2, p. 650, 652, 1910.

[10] This section in 2022 has been restored back to the original paper manuscript of circa 1924 which better reflects Waldemar Schaller's personal history of how this book was prepared.

[11] See bibliography pages for references

collections were visited and special attention was given to minerals from European localities. I was thus able to establish the identity of several of the phosphate minerals from Pala with material from France. The investigation of the California materials was finally completed and the report was submitted for publication in June, 1913. Most of the investigations of the California minerals had to be carried on during short respites from the regular routine work of the chemical laboratory of the USGS, so that a single study was often carried on for several years before it could be finished.

The descriptions of mines given in this report are based rather on the scientific interest than on the money value of the deposits. The length of the description is, therefore, no criterion as to the value of the mine. Difficulty of admittance to the mines and of collection of material for study necessarily also affected the fullness of the descriptions.

Acknowledgments

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Among my many friends in California, to whom I am under deep obligations and to whom I can but take this opportunity to express my very best thanks for their numerous favors, are legion, and if I fail to give their names it is only because I can not extend the list too far.[12] Special and grateful mention is made of Prof. A. C. Lawson and Prof. A.S. Eakle, of the University of California, and of the following gentlemen in southern California: Messrs, H. C. Gordon, and Frank A. Salmons, John J. Mack, A. Fano, and Fred Rynerson, of San Diego; Messrs. John Reed, John Giddens, M. M. and P. M. Sickler, Bernardo Hiriart, Pedro Teiletch, A. Golsh, O. C. Harrington, F. A. Moreno, and Ollie Fields, of Pala; Mr. T. A. Freeman, of Bonsall; Messrs. J. D. Farley, J. B. Booth, A. W. Prey, Charles P. Boyd, D. Mcintosh, Jr., and A. B. Daggett, of Ramona; Messrs. C. O. McCarroll, Arthur Watkins, J. Goodman Braye, Jr., Vance Angel, and Frank Trask, of Mesa Grande; Mr. H. E. Dougherty, of Hemet; the San Diego Tourmaline Mining Co., through Mr. K. C. Naylor and Mr. A. L. Ross, and the Naylor Gem Co., successor to the first- named company, through Messrs. K. C. and H. Naylor. In addition special thanks are due to Mr. S. C. Smith, of Keystone, S. Dakota; and to Messrs. W. N. McCrillis, of Rumford, and L. B. Merrill, of Paris, and to Mrs. W. R. Wade, of Lewiston, Maine.

Previous Work

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[12] Restored text from original 1924 text.

The literature[13] bearing on the mineralogy of the southern California gem tourmaline field is not extensive. Several earlier papers relate in a general way to the tourmaline and lepidolite and their occurrence. The paper by Fairbanks in the eleventh report of the California State Mineralogist is the only one which gives a description of the geology of the region. The structure of the gem and lithia bearing formation is described by Waring and the associations of the minerals at Rincon by Rogers. The annual reports on precious stones in the volumes of Mineral Resources of the US contain good descriptions of occurrences.

The best and most complete report on the field, so far published, is Bulletin No. 37 of the California State Mining Bureau. This was written by Dr. G.F. Kunz and gives a good idea of the general features of the region. Kunz has also written numerous papers on the lilac spodumene, especially on its unique properties with regard to light effects. A short note on the general properties of the spodumene was also published by the writer. The tourmalines from Mesa Grande were described briefly by Sterrett, and Ford has written two papers on the relations of the physical properties of beryl to its chemical composition. The only complete mineralogical paper on this area is the one by Penfield and Ford on stibiotantalite, which describes the mineral most fully.

Bibliography

The following bibliography is intended to include all papers relating to the mineralogy of the region and all that consider the geology in its bearing on the minerals of the area. The list does not include popular magazine and newspaper articles describing the tourmaline and kunzite except those that contain original matter. A few references have been included largely on account of their historical interest. The bibliography is intended to include all papers appearing before December 31, 1910.

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Blake, W.P. Geological Report: U.S. Pacific R.R. Exped., 1856 (Williamson), vol. 5, pt. 2, p. 304, 1857. Mentions occurrence of immense black tourmaline in feldspathic veins, north side of San Felipe Valley, California.

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[13] See Bibliography, pages x.

on the minerals of the area. Also figures of production and value.

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_____. Notes on the occurrence of rubellite and lepidolite in southern California: Science, new ser., vol. 21, p. 35-36, issue 520, January 20, 1893. A general description of the large pegmatite on Stewart Hill. Nine minerals are mentioned as found here-quartz, feldspar, muscovite, garnet, hematite, oligoclase, and green, red, and black tourmaline. [The list, which should include lepidolite, contains only 8 mineral species. This number has now been increased to twenty for the Stewart mine].

Farrington, O.C. Gems and gem minerals, 1903. Contains colored illustration of rubellite in lepidolite. [From Stewart mine, Pala].

Ford, W.E. Some interesting beryl crystals and their associations: Am. Jour. Sci., 4th ser., vol. 22, pp. 217-223, 1906. Describes the crystal forms and habit of pink beryls from Mesa Grande and Pala and from localities outside of California, and of the green beryls from Rincon. The relations in habit to chemical composition are discussed. The remarkable etchings on the beryls from Ramona are also described.

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Part II. The ore minerals, geology, and paragenesis of the pegmatites

Minerals Mined

Uses of the Minerals

Deposits of lithium minerals in California have been sought because of their gem stones and because of their value as sources of manufactured sales of lithium. The use of gem stones as jewels for personal adornment furnishes their largest market. The beauty of cut spodumene (variety kunzite) can be seen from Plate XXXI, page

The specimens obtained from many of the mines of this field are so beautiful that they represent a considerable value and there has been an extensive trade in them ever since the mines were first opened. The value of many of the stones found is much greater as specimens than as gems, but gems are so much more salable that many unique specimens have been destroyed in order to get quickly the much smaller price represented by the parts of the stones that were of value as gems. The value of a specimen depends entire on individual; appraisal; it can be determined by no general rule.

Many of the minerals found here would make valuable decorative stones, but this industry has not been developed in California. The massive lepidolite having included radiating pink tourmalines could be easily turned into vases or paper weights. Many other mineral associations, such as graphic granite or quartz and feldspar having included colored tourmalines, could be utilized in a similar way.

The lithium minerals lepidolite and amblygonite furnish a source of manufactured salts of lithium used medicinally as artificial lithia waters and lithia tablets. Haywood and Smith[14] describe the medicinal use of lithium mineral waters as follows:

While lithium seldom or never occurs in waters in large enough quantities to be a predominating basic constituent, still it does often appear in sufficient quantities to have a decided therapeutic action. These compounds are active diuretics and form a very soluble urate which Is easily eliminated from the system. Waters of the above class therefore find their greatest application in the treatment of rheumatism, rheumatic tendencies, and gout. In cases of gravel and calculi they are also valuable disintegrating agents.

Other uses of lithium salts are in photography, fireworks, and in the manufacture of storage batteries.[15]

The most important manufactured salts of lithium are the bromide (used in photography), carbonate, phosphate, and citrate. Lithium carbonate is a white powder, slightly soluble in pure water but more soluble in water containing carbonic acid. It is used in medicine for removing pathological deposits of uric acid in the body, being administered in the form of a solution in carbonic acid water. The usefulness of

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[14] Haywood, J.K, and Smith, B.H., Mineral waters of the United States: U.S. Dept. Ag;. Bur. Chemistry Bull. 91, p. 12, 1905.

[15] Hess, F.L., Lithium in 1909: U.S. Geological Survey Mineral Resources U.S., p. 6, 1909, 1910.

lithium salts for this purpose has, however, been recently questioned. Lithium citrate has been used in medicine in place of the carbonate; its therapeutic action is similar.

An article on the manufacture of lithia salts from lepidolite states[16] that the maximum yield obtained on the industrial scale was 97 per cent, the average being 94 per cent. The cost of process appeared to be about 97-1/2 cents per pound of lithia, or a net cost, allowing for value of alum produced, of 77-1/2 cents per pound. The following quantities represent operations during four weeks. Lepidolite 7,200 pounds, sulphuric acid 7,920 pounds, potassium carbonate 1,602 pounds, whiting 1,224 pounds, oxalic acid 105 pounds, ammonia 105 pounds. Five men were employed during the four weeks. The products obtained were: Lithium carbonate 513 pounds, and alum meal 6,009 pounds. In percentage of possible quantity, the yields were 39 per cent alum, 60.8 per cent lithium carbonate, and 34 per cent potassium oxide (K_2O). The losses amounted to about 9,000 pounds alum, 320 pounds lithium carbonate, and about 1,165 pounds actual potash. No potash was recovered from the ore as there was an actual deficit of 265 pounds potash from that added as carbonate.

Some confusion exists in regard to the names for the ores and compounds of lithium, and the following definitions are given to enable the reader to understand clearly what is meant by the various terms.

Lithium is the name given to an elementary substance which is present, in combination, in all these minerals. It is a silver white, very soft metal, which cannot remain exposed to the air without forming the oxide or some other salt. It decomposes water, forming the hydroxide of lithium and for this reason the metal lithium cannot be found in nature as such. Compounds are called lithium carbonate, lithium phosphate, and lithium silicate.

Lithia, the oxide of lithium, is a white solid, soluble in water; it also readily undergoes change on exposure to the air. It has not thus far been found in nature and its instability in air and solubility in water will probably prevent its ever being found as a natural mineral. The term lithia is, however, also popularly applied to lithium carbonate, which application has caused some confusion. The latter use is erroneous; the term lithia should be used only for the oxide of lithium. The carbonate of lithium could exist in nature under conditions similar to those under which the carbonate of sodium is found, but the scarcity of lithium minerals prevents the natural accumulation of any deposit of lithium carbonate.

Lithium mica, (not lithia mica) is a name often given to lepidolite, a mica containing about 4 per cent of lithia. The term mica lithia has no meaning, and the term lithia rock which has been used to designate the Pala lepidolite should give way to lithium mica or lepidolite. Lithium mica is a general term used to designate any mica containing an appreciable quantity of lithium in combination. Lepidolite is the most common of these lithium micas, but several others are known, such as zinnwaldite, cryophyllite, polylithionite, protolithionite, irvingite, and taeniolite. Cookeite, also a micaceous mineral containing lithium, has likewise erroneously been called "lithia".

Gem Minerals

Tourmaline

The name tourmaline[17] is applied to a group or series of minerals, very

[16] Shieffelin, W.J. and Cappon, T.W., The manufacture of lithia from lepidolite: Soc. Chem. Industry Jour., vol. 27, no. 11, p. 549, 1908.

[17] The group name tourmaline has been used throughout Part II.

widespread in their occurrence and found in a large number of different kinds of rock. Their composition is somewhat similar in general, but in detail it varies in the different members of the series. Tourmaline is a complex silicate and its varieties contain alumina, boric oxide, soda, and water and some kinds have either magnesia or iron present in large amounts. Other varieties contain lithia, manganese, calcium, fluorine, and even additional chemical elements in their composition.

Three species of tourmalines are generally recognized as being, chemically, fairly distinct. These are (1) the gem or lithium tourmalines which, found in green, blue, pink, and other colors, are valuable and form the most important mineral described in this report (2) the iron tourmalines, abundant throughout the field as large black crystals, and (3) the magnesium tourmalines, not found directly associated with the tourmalines of southern California.

The gem or lithium tourmaline is very remarkable for the number of colors and shades in which its crystals are found. Though several other gem minerals, such as diamond and corundum, have been found in almost all colors, there is probably no mineral which can show in its natural state so diverse a coloring scheme as lithium tourmalines.

The transparent crystals are naturally the most valuable and are cut into facetted stones, but some other tourmalines make very beautiful cabochon stones, especially those that show a cat's-eye or chatoyant effect, as many of the California tourmalines do. A very marked feature of the colored tourmalines is their dichroism which means that the color is different when a crystal is viewed across its length from that which is seen when viewed parallel to its length. The difference in color may be only one of intensity or the two colors may be entirely distinct.

The black and very dark blue colors, as well as some of the greens, are due to iron; the pink and red are due to manganese. It must be remembered, however, that the colors we see in the crystals are the results of the combination of two or more distinct colors. Thus the purple sometimes seen is due to the combination of the red and blue. The lack of color in some crystals is not necessarily due to the absence of either iron or manganese, but to their compensating effect; that is, the red and the green may neutralize each other so that the crystal appears nearly colorless.

The variously colored tourmalines have received names which refer almost entirely to their color and some of the names have been specially applied to the tourmalines from a certain locality. These different names are given below:

Black	Schorl.
Black, from Norway..........................	aphrizite.
Red and pink	rubellite.
Violet-red, from Siberia....................	siberite.
Deep Berlin - blue, from Brazil	Brazilian sapphire.
Blue and bluish - black....................	indicolite.
Bright green, from Brazil.................	Brazilian emerald.
Yellow green, from Ceylon............	Ceylonese chrysolite or peridot.
Colorless	achroite.
Brown, from Austria	dravite

The mineral usually occurs in prisms, which may be in distinct crystals or in radiated aggregates or in irregular masses, the crystals being without any regular grouping. These prisms vary greatly in size. They may form hair like needles, and they may vary from the size of a pencil to prisms several feet long and many inches thick. The prism faces are vertically striated and this commonly gives the crystals a rounded

appearance. The cross sections of a crystal have usually three, six, or nine sides. When naturally terminated the terminal facets are seldom the same at both ends (hemimorphic).

Tourmaline has no cleavage; it is very brittle; its hardness is 7 to 7.5, and its specific gravity 3.0 to 3.2. It occurs in all colors and shades. A very common feature is that the two ends of one crystal are differently colored; crystals green at one end and red or pink at the other are often seen. It is also common to find a crystal possessing a core of one color and a shell of a different color. A red core and a green or blue shell are of frequent occurrence. Only a very small proportion of the tourmalines found in nature are transparent enough to be valuable as gems. The variation in chemical composition of the three kinds of tourmaline are shown in the table below.

Composition of different tourmalines.

	Lithium tourmaline	Iron tourmaline	Magnesium tourmaline
	(Elbaite)	(Schorlite)	
	Colorless, red, green, blue	Black to very to dark blue	Colorless, black, brown
Oxide	Per cent	Per cent	Per cent
SiO_2	38-36	36-34	38-35
B_2O_3	10-11	10-11	10-11
Al_2O_3	44-38	37-33	32-25
FeO + MnO	0-5	10- 17	0-8
MgO	0	0-1	0-5
CaO	0-1	0-1	0-5
Na_2O	2-3	2-3	1-2
Li_2O	1-2	0	0
H_2O	3-4	3-4	3-4

The most important foreign localities for lithium tourmalines are in the Ural Mountains, Russia; the island of Elba, Italy; and in the vicinity of Antsirabe, Madagascar. These occurrences are briefly described later in this paper (commencing on p. are in Maine, Connecticut, Massachusetts, and California). In the United States, the chief localities

Spodumene

Spodumene is a silicate of alumina and lithia, with the formula $Li_2O \cdot Al_2O_3 \cdot 4SiO_2$. Minute quantities of other bases, such as soda or manganese, are sometimes present. This mineral is found in distinct crystals which are often very large, reaching in South Dakota a length of 40 feet. The crystals may be rounded, or nearly square, or flat and tabular. They possess a perfect prismatic cleavage, with an angle of 93° and 87°; also in some specimens a cleavage or parting parallel to the large flat face a {100}. The mineral rarely occurs as clear and transparent crystals, the usual mode of occurrence being as greyish-white, opaque masses. The clear, transparent varieties have been found colorless, pink, lilac, green, yellow, and blue; and to some of them variety names have been applied as follows: the green varieties is called hiddenite, the yellow is triphane or Brazilian chrysoberyl, and the pink and lilac is kunzite. The

hardness of the mineral varies from 6.5 to 7, and the specific gravity is about 3.17. The mineral readily undergoes alteration into a mixture of albite and muscovite, or into mica alone, and also sometimes into clay. The theoretical chemical composition of unaltered spodumene is as follows:

Theoretical composition of spodumene.

Silica (SiO2) 64.7
Alumina (Al2O3).. 27.3
Lithia (Li2O) .... <u>8.0</u>
total ·· ·················· 100.0

Before the blowpipe the mineral fuses easily to a whitish glass, at the same time giving the flame the characteristic deep crimson color. This flame test, together with the high specific gravity and perfect cleavage, should determine spodumene without any difficulty.

The green spodumene, or hiddenite, was found in North Carolina about 30 years ago in small, clear, transparent crystals of a beautiful deep green color shading into yellow. Only a limited quantity was found. The yellow or yellowish-green variety, triphane, comes from Brazil where it occurs as loose pieces in the disintegrated rock. It was at first taken for chrysoberyl, which it greatly resembles, and in this way it got its name of Brazilian chrysoberyl. The lilac spodumene, kunzite, comes from San Diego County, California, where it was reported to have been first found in 1902. The occurrence of large, clear, transparent crystals of lilac spodumene was a very noteworthy discovery, and the mineral was first identified by Mr. G.F. Kunz, in whose honor it was named kunzite by Prof. Charles Baskerville. The pink, transparent spodumene, found in Connecticut some 25 years ago, is doubtless the same as the kunzite of California, although the latter has a deep violet color that the Connecticut mineral does not possess. The Connecticut spodumene is of no value as a gem, being too poor in quality and occurring in too small quantity, whereas the California kunzite occurs in large quantity, is very suitable for jewelry, and gems of any desired form have been cut from it, the two shown on Plate xx weighing carats, respectively.[18] Pink, transparent spodumene has also been found in Madagascar.[19] The transparent varieties of spodumene are generally in crystals, which are remarkably etched and rounded. A blue transparent spodumene has also been found in Brazil.

Beryl

The mineral beryl is a silicate of alumina and beryllia, a little water being also present. In some beryls, however, the alkali metals, especially sodium, lithium, and caesium, partly replace the beryllia, and then the habit of the crystals charge and also the physical properties of the mineral.

Beryl is generally found in long, six-sided prisms, though in the alkali varieties, as mentioned above, the crystals are more tabular and equidimensional in shape. Beryl is found in many colors and often is sufficiently transparent to be used as a gem stone. When so suitable, it may become very valuable, as the well-known emerald testifies. The names given to the different colored beryls used as gems are as follows:

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[18] Kunz, G.F., U.S. Geol. Survey, Mineral Resources U.S., 1903, p. 946, 1904
[19] See page x.

Green.. emerald.
Pale blue, bluish-green,
   greenish-blue, or pale-green .... aquamarine.
Yellow-green .... aquamarine chrysolite.
Bright yellow... golden beryl.
Pink, from Madagascar .... morganite.
Blue, violet .... no special names.

The hardness of beryl is about 7.5 and its specific gravity is from 2.65 to 2.75. It is practically infusible in the blowpipe flame. It has no cleavage and its six-sided crystals may be distinguished from those of quartz-perhaps the only mineral from which confusion might arise-by the fact that in beryl the six prism faces are striated parallel to their intersection while in quartz the striae are normal to the edges of the prism faces. Aquamarine, common yellow, colorless, and pink beryls have been found in the California field. The pink beryls are rich in alkalies, several per cent of lithia and caesia being present.

Garnet

The term garnet refers to a group of minerals that includes several well-defined species, distinguished by a needlessly large number of names. Garnet is a very common mineral and is found in many kinds of rock. Its most common color is some shade of red, but garnet of other colors, notably white, yellow, green, black, or brown are also found. Only those garnets that possess a good color and that can be obtained in large, clear pieces are of value as gems.

Garnets are generally found in equidimensional crystals, which, when complete, have 12 faces or some multiple thereof. The mineral does not possess cleavage, has a hardness of from 6.5 to 7.5, in ranges in density from 3 to over 4.

The following names given to the various species of garnets are based solely on the chemical composition. Color is not an infallible guide and, in general, it is not possible to determine to which species certain garnets belong without a chemical analysis.

Aluminum-calcium garnet	Grossularite or essonite, cinnamon stone.
Aluminum-magnesium garnet	Pyrope, Arizona ruby.
Aluminum-iron (ferrous) garnet	Almandite, common garnet.
Aluminum-manganese garnet	.Spessartite.
Iron (ferric)-calcium garnet	Andradite, common garnet, demantoid (green), topazolite (yellow), melanite (black), colophonite (brown).
Chromium (and aluminum)-calcium garnet	Uvarovite.

Many other names, rhodolite, aplome, titaniferous garnet have been applied to various mixtures of these species. Hyacinth is a name sometimes applied to yellow or brown essonite garnets, but the name belongs properly to the mineral zircon.

Of the above-named garnets, only spessartite and almandite have been found in the field here described.

Other gem minerals.

The other gem minerals which have been mined in the area under consideration are quartz, topaz, epidote, and axinite. Faceted stones have also been cut from feldspar, stibiotantalite, and apatite though they have very little, if any, commercial value.

The quartz crystals, so abundant in nearly all the pegmatites, are often sufficiently clear to yield good gem stones; and colorless, yellow, and smoky quartz have been so used. The topaz crystals found at Ramona have also furnished material suitable for gems, either colorless or pale blue. A small part of the epidote and axinite found yielded clear stones, but the total quantity of this material of gem value is not large.

For cabochon cutting, the minerals have not been used to their advantage. Cabochon stones have been cut of many of the gems mentioned, but a large amount of additional material, such as quartz, colored by various inclusions; intergrowths of several kinds of feldspars and of the finer grained graphic granite; different intergrowths of quartz with black tourmaline or with brown garnet, could all be used to good advantage.

Lithium ores

Lepidolite.

Lepidolite or lithium mica is a silicate of aluminum, potassium, and lithium, containing also fluorine, water, and small quantities of sodium, iron, and manganese. Some of the minerals which have thus far been found to be almost invariably present with it are pink, blue, and green tourmalines, albite in large white tabular crystals, orthoclase, microcline, quartz, and muscovite. Lithium mica usually occurs as a fine-grained, scaly aggregate of a whitish to pink or purple color; it occurs also in coarser scales, often of a deep red, purple, or blue color, which may in rare instances reach a diameter of several inches. Very rarely it has a greenish or yellowish-green color. It frequently occurs as a narrow border on plates of muscovite, such an association having been observed at nearly all the localities where the mineral has been found. Lepidolite, like all true micas, can be cleaved off into thin plates, which, if not too thick, are elastic. The hardness is about 3, but varies, and the specific gravity is 2.8 to 2.9. The mineral is not known to undergo alteration or decomposition. The chemical composition varies somewhat, and the following analysis may be taken as showing the approximate constitution of typical lepidolite:

Composition of typical lepidolite (in weight percent).

Silica, (SiO2) .	51
Alumina (,Al2O3)..	11
Potash, (K2O)	11
Soda, (Na2O).	1
Lithia, (Li2O)	4
Water, (H2O).	2
Fluorine. (F)	7
Total	103
Less oxygen (0) for fluorine (F)	3
Total	100

Before the blowpipe, the mineral fuses very easily to a white glass, at the same time coloring the flame a deep crimson. The scaly or micaceous character of the mineral, its softness, its color, and especially the blowpipe reaction just mentioned will serve to identify and distinguish lepidolite from other minerals.

Lepidolite has been found at numerous places but it seldom occurs in quantity. Some of the chief foreign localities are Uto in Sweden, Bohemia and Moravia in Austria-Hungary, the Urals in Russia, Elba in Italy, and near Montebras in France. In the United States it is found in Maine, Massachusetts, Connecticut, South Dakota, Colorado, and California. It is mined as lithium ore in Moravia, Austria; Chanteloube, France; and Pala, California.

Amblygonite.

Amblygonite is a phosphate of aluminum and lithium, with fluorine and water. It is a rare mineral and is usually found only in small quantities[20] but at one time developments at Pala, California, exposed a large mass of pure amblygonite containing several hundreds of tons. It is a nearly white mineral, usually occurring massive, rarely in crystals, and possessing one good cleavage. It resembles white feldspar and to some extent also white spodumene. It has a hardness of 6 and a specific gravity of 3.0 to 3.1. Its usual color is white, but it has been found with a greenish, bluish, yellowish, greyish, or brownish cast. In some varieties there is much fluorine and little water; in others there is much water and little fluorine; but all the amblygonite analyzed from California contains both water and fluorine. The average composition may be expressed as follows:

Composition of typical amblygonite.

Phosphoric acid (P2O5)...	48
Alumina (Al2O3)...	33
Lithia (Li2O)	10
Water (H2O)..	5
Fluorine (F)	6
Total ……………………………………………………	102

[20] Several hundred tons have also been mined in South Dakota; See page.

Less oxygen (O) for fluorine (F) .... <u>2</u>
Total   …………………………………………… 100

Before the blowpipe the mineral fuses easily to an opaque white mass, coloring the flame red. Its high specific gravity (3.1) makes it feel heavy when compared, for instance, with feldspar (2.65). The principal localities where it has been found are in Saxony, Germany; Montebras, France; Northern Territory, Australia, and in Maine, South Dakota, and California. Amblygonite has been mined commercially at Montebras, France; Northern Territory, Australia, Black Hills, South Dakota; and Pala, California.

Other minerals of possible value

In addition to the gem and lithium minerals briefly described in the preceding paragraphs, there are in this area other minerals of economic value. The occurrences of these other minerals may prove of considerable value when the California localities have been more developed and when the costs of transportation are not so great as they are today.

The potash feldspar and the quartz of pegmatite dikes are mined at a profit in several of the Eastern States, the feldspar being used for the manufacture of pottery, enamel ware, enamel brick, and electrical ware. Other uses to which feldspar is put are in the manufacture of emery and corundum wheels, opalescent glass, poultry grit, roofing material, ballast, artificial teeth, and for scouring soaps and window wash.

The quartz is used to a small extent for jewelry, the transparent crystals and the smoky and rose quartz being available for gem stones. The massive quartz, such as occurs abundantly with the feldspar, is used for many purposes; the principal ones being in the manufacture of pottery, paints, scouring soap, and as a wood filler. It also finds extensive use as an abrasive.

Muscovite, the common mica of pegmatites, is valuable when found in large sheets because it is transparent, flexible, elastic, and a nonconductor of heat and electricity. It is used for stove and lamp chimneys and in the manufacture of electrical apparatus. Ground mica also finds extensive miscellaneous use.

Other minerals such as wolframite, columbite, cassiterite, and the rare-earth minerals containing yttrium, thorium, and cerium, are also found in quantity in some pegmatites. Uranium minerals, such as pitchblende, occur in sufficient abundance to pay for their extraction in some pegmatites.

The possibility of the occurrence and use of these minerals indicate a possible source of value in the California pegmatites that should not be overlooked.

Geology

Geological history

The oldest rocks of the region are a series of metamorphic slates, schists, and gneisses, which according to Fairbanks run through the heart of the Peninsular Range from the Mexican line through the Santa Anna Mountains. The gold mines of Julian, in San Diego County, are in this schist belt, which has an extension from north to south of more than a hundred miles. Part of these metamorphic rocks are of sedimentary origin and part are more or less metamorphosed igneous rocks. E.S. Larsen, of the U.S. Geological Survey, has determined that some of the slates and schists of the Santa Anna Mountains are of Jurassic age.

The greater part of the tourmaline field and of the country north, east, and south of it, is composed of igneous rocks of late Mesozoic age. These igneous rocks are chiefly made up of a light- colored, persilicic rock of essentially a granitic character. A smaller quantity of a dark-colored, subsilicic rock of a gabbroitic nature is associated with the granitic rocks and apparently intrusive into them. Though intermediate rocks were noted, no actual gradation of a granitic to a gabbroitic rock was observed in the vicinity of the tourmaline mines. Most of the granitic rock is a granite and similarly most of the gabbroitic rock is gabbro, and where these are in conjunction their contact is always sharp and distinct and the observed phenomena indicate that in most cases the gabbro is intrusive into the granite. Later smaller granite intrusions into the gabbro also occur.

Pegmatite dikes of a granitic type and composed essentially of quartz and feldspar abound in both the granite and gabbro and it is in these dikes and especially in such ones as intrude the gabbro, that the lithium and gem minerals of the tourmaline field are found. The pegmatites are described in detail in the following pages, where, for convenience of description they are classified into three types, namely, the homogeneous type, the symmetrical type, and the asymmetrical type. In the discussion as to the origin of these pegmatite dikes (pp.   to   ), it is brought out that these three types result from the genetic conditions which obtained at the time of their intrusion into the fissures which they now fill.

The granitic rocks are soon distinguished from the gabbroitic rocks by certain differences in the appearance of the hill sides. The hills composed of granitic rocks are thickly covered \\ith bare rock, often in large bowlders, with ragged bold exposures; the soil is scanty and of a greyish color, when viewed from a distance. The hills composed of gabbroitic rocks, on the contrary, usually appear free of any large exposures of rock21 Owing perhaps to the more ready decomposition of the gabbro as well as to its darker color. The soil, resulting from the disintegration of these gabbroitic rocks, is brownish red and often gives the land a striking reddish color. Sometimes, however, the pegmatites in the gabbro are so numerous as almost to give the hill a granitic appearance. On close inspection, their form can usually be seen and the reddish soil between them made out.

A long period of erosion ensued after the eruption of the granites and gabbros and a series of late cretaceous and tertiary sediments formed, which are today exposed along the shore line of the Pacific Ocean. The sediments consist largely of conglomerates and gravels, though shales, sandstones, and smaller bodies of limestone are also present. Effusive volcanic rocks occupy a very small area of the tourmaline field, but southward, toward San Diego City, and still further south, they are much more abundant. Fairbanks states:

"The numerous eruptions of lava in the region explored are of late Tertiary age. At that time a decided uplift, accompanied by faulting, took place, and as a result of this uplift fissures were formed through which the lava flowed. There are no signs of volcanoes."

Quaternary gravels and clays cover only small areas of the tourmaline field, such as that of Warner's Ranch, east of Mesa Grande, but on the eastern side of the Peninsular Range, these sediments are more abundant. Fairbanks says:

"Everything points to a very recent submergence of the Colorado desert. It is

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[21] This is well shown in the photograph of Stewart Hill, Plate XV, P.

probable that during Quaternary times, the whole mountain range was submerged between 2,000 and 3,000 feet, and that the great beds of unconsolidated gravels and bowlders, which overlie the Tertiary, were then formed. The country rose at the begnning of the Modern period, and the deep canons have largely been eroded since."

Granite and related rocks

The granitic rocks largely consist of granite, which is composed of orthoclase, quartz, and mica (at some places biotite, at other muscovite, and often both together). Numerous variations from the normal granite were observed, and particularly to be noted was the presence of hornblende, forming hornblende granite. By the addition of plagioclase feldspar the rock grades into a quartz diorite, and still more marked changes could be found at the various localities. Fairbanks mapped granite, gneiss, syenite, and diorite together, and the term granitic rocks as here used is seen to include an extensive series of rocks different, possessing such characteristics in common that they may be, as a class, sharply distinguished from the gabbroitic rocks.

The pegmatites containing the gem tourmalines are, with only one well defined exception, in gabbro, which is surrounded by granite, so that granitic rocks in large masses are always present in the near vicinity of the pegmatites. The single exception noted, where the gem-bearing pegmatite dike is in granite (quartz, orthoclase, and a little biotite) is near Red Mountain, Riverside County, and lies in a very extensive granitic region, extending west from the San Jacinto Mountains. No rock resembling a gabbro was noticed in the vicinity of the dike.

Gabbro and related rocks

General features

The gabbro is generally a coarse-grained, heavy, dark rock, and consists of a white feldspar and one or more black ferromagnesian minerals. The feldspar weathers away more quickly than the ferromagnesian minerals, with the result that the latter stand out in strong relief on the exposed surfaces of the rock. The texture of the rock varies considerably from very fine grained to very coarse. Owing to a predominance of either of the feldspar or the ferromagnesian minerals, the rock locally is either very light or very dark, though the light color is of rare occurrence. The feldspar is fairly uniformly labradorite. In a few cases it becomes more calcic, grading toward bytownite. Green hornblende is the most abundant ferromagnesian mineral and at many places forms with labradorite the essential constituents of the rock. Other ferromagnesian minerals present are brown hornblende, augite, hypersthene, olivine, and biotite. The accessory minerals are magnetite, apatite, and ilmenite. A small amount of secondary hornblende, biotite, chlorite, and hematite, is developed at places.

The gabbro areas are of considerable size, many of them extending several miles. Small dikes, a few inches in width and containing the same minerals as the surrounding rock, but with one or the other predominating, frequently cut through the gabbro in all directions and are sometimes intercepted by the pegmatites. Their shortness, narrowness, and irregularity in direction, suggest that these dikes are filled contraction fissures.

A detailed petrographic study of a large number of specimens has shown that the ferromagnesian minerals of the gabbro unit, as it may be called, vary considerably

even in a small extent of country. It was found by microscopic study that the very coarse-grained gabbro usually consists of only hornblende and feldspar, whereas the fine-grained varieties usually contain also olivine and hypersthene. It may be that the texture is, to some extent at least, influenced by the composition of the rock magma. So far as the rock mass has been studied, there does not appear to be any relation between the presence of the lithium-bearing pegmatite dikes and the variations in the gabbro.

Local variations.

Most of the gabbro at Pala consists of green hornblende and labradorite. Some specimens from Stewart Hill contain olivine, augite, hypersthene, and labradorite with subordinate hornblende, and another phase consists chiefly of hypersthene and labradorite. The hornblende-labradorite phase is, however, the most abundant and is the characteristic variety of gabbro for the region around Pala. At the Tourmaline Queen mine the gabbro has a lighter color due to the preponderance of the feldspar. At the base of Pala Chief Hill, on the western side, the gabbro is coarse grained with a little hornblende and feldspar, so that the resulting soil has a grayish color and resembles more the granitic than the usually red gabbro soil. The gabbro at the Pala Chief mine at the top of the hill consists essentially of hornblende and labradorite, with a very little orthoclase. On the summit of Hiriart Hill, the gabbro becomes exceedingly coarse, some individual crystals being several centimeters long. An orbicular phase of the rock is here developed, only the orbicules remaining, the remainder of the rock having weathered away[22]. The gabbro of the entire hill shows essentially only hornblende and labradorite.

The gabbro at Bonsall was not studied microscopically, but in the field its appearance is similar to that at Pala. At Rincon the country rock is medium grained and shows crystals of hornblende, black lustrous biotite, and a gray feldspar. Microscopically, the rock is seen to consist chiefly of green hornblende and labradorite, with smaller amounts of biotite, quartz, and hypersthene.

At Mesa Grande the gabbro contains augite, hypersthene, and labradorite, with smaller quantities of brown and green hornblende, and accessory biotite and magnetite. In thin section the augite is very light gray to colorless; and nonpleochroic. Inclusions are frequent and consist mostly of brown hornblende, hypersthene, feldspar, and iron oxides. Some of the augite has become uralized to fibrous green hornblende, the extent of the alteration being at times considerable. The hypersthene usually occurs in hypidiomorphic forms, with strong pleochroism.

At Ramona the rock has the character of a norite, being composed of hypersthene, labradorite, and small quantities of biotite, augite, and hornblende, with accessory apatite and magnetite. The hypersthene is very abundant in hypidiomorphic, pleochroic masses and prisms; the biotite occurs in large scales, with many inclusions of feldspar and a smaller number of hypersthene; the augite occurs in irregular, nonpleochroic masses, with high relief and birefringence; and the hornblende is sparingly present as a green, pleochroic rim surrounding the hypersthene.

The gabbro at Oak Grove and Coahuila contains much olivine. Specimens from Oak Grove show a mottled rock with large phenocrysts of hornblende averaging about 3 by 2 centimeters, and some even larger. The cleavage surfaces of the hornblende are full of feldspar inclusions, which often weather away leaving the surfaces very

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[22] Schaller, W.T., Orbicular gabbro from Pala, San Diego County, California: U.S. Geol. Survey Bull. 490, p. 58, 1911.

much pitted. The other minerals present are olivine, labradorite, hypersthene, augite, and magnetite. At Coahuila, the rock consists of hornblende, olivine, hypersthene, chlorite, and labradorite, with accessory magnetite. The green hornblende is largely converted to chlorite. Hypersthene is fairly plentiful, occurring in prismatic idiomorphic forms and also in small areas of irregular contour. It is full of small inclusions. It is almost colorless, has a high relief and a low birefringence, and is not strongly pleochroic. Like the hornblende, it seems to alter to chlorite. The olivine, partly altered, shows its usual form and properties.

Alteration

In the development of the gem mining, several small shafts and open cuts were made in the gabbro where no pegmatite was encountered. The numerous road cuttings also exposed the gabbro at places where there is no pegmatite to be seen. In all these places, the gabbro was identical with that exposed in the workings of the mines where the shafts and tunnels followed the pegmatite dikes.

At all of the exposed places the gabbro is changed from a hard compact rock to loose, soft, gray dirt having a greenish tint. Where exposed to the air the gray color is changed to a brownish red by oxidation of the iron. The gray dirt is so soft that it can be easily dug into with the fingers. In this soft material are hard residual bowlders or spheroidal nuclei of the unaltered gabbro, many of which are surrounded by layers of progressively more and more loose and crumbly material. Plate II A. shows a residual bowlder embedded in the loose dirt which admirably illustrates the process of decomposition, so aptly called spheroidal weathering. As the surface of the land is gradually lowered by erosion, the soft interstitial dirt is washed away and a natural concentration of these hard bowlders takes place at the surface. The result is that the surface of a gabbro rock mass is formed by a deposit of these rounded bowlders, which, with some dirt and the low vegetation, forms a relatively plane surface. This is why the gabbroitic hills generally appear free of any large rock exposures. The gabbro above the faulted pegmatite dike (Pl. II B) is entirely altered to a loose dirt.

The mineral change in the rock is first the kaolinization of the feldspar and finally the breaking down of the ferromagnesian mineral into iron oxides. Much of the loose dirt still contains numerous fresh, pleochroic, hornblende prisms, showing that the change of the feldspar causes the disintegration of the rock. At one place (Mesa Grande) where the white color of the dirt showed that the rock had locally consisted largely of feldspar, a determination of the loss in ignition (water) was made on an air dried sample, which was free from any carbonate. The loss was 12.17 per cent, and as kaolin contains 14.0 per cent water, the feldspar had probably largely changed to kaolin.

Where these hard residual bowlders were found adjoining the pegmatite dikes no differences could be found between them and the bowlders a considerable distance away from any pegmatite mass. At the Stewart mine at Pala, a number of loose gabbro bowlders, found near the upper contact of the pegmatite and the country rock, have on one side a thick layer of radiating black tourmaline crystals. A thin section of the gabbro showed no effect of this deposition of tourmaline crystals, coming from the pegmatite.

No minerals were found in any part of the gabbro which could have resulted from the action of gases and solutions emanating from the pegmatite. The black tourmaline crystals above mentioned do not penetrate the gabbro bowlders, which evidently must have been right at the contact.

In some of the deeper tunnels at Mesa Grande the extent of firm rock is much greater than nearer, the surface but even at the greatest depths the gabbro is

extensively decomposed. The change of the gabbro from a firm rock to a loose dirt can hardly be ascribed to any other cause than that of weathering. The residual bowlders are not caused by any orbicular structure of the rock, and its component minerals in no case show an orientation corresponding to the spheroidal shape of the bowlders. They undoubtedly are the result of fissuring of the gabbro, which broke it up into numerous units. The weathering and decomposition agencies then found these fissures avenues of easy access and the resultant residual bowlders of firm rock would naturally tend toward a spheroidal shape. This kind of weathering is common and has been described in detail for many occurrences.

The description of the alteration of the gabbro has been here given at some length, as it is important to show that the alteration cannot be connected in any way with the presence of the pegmatites. In fact nothing was observed which indicates that the intrusion of the pegmatites has effected the gabbro in anyway.

Granitic pegmatites

General features.

The granitic pegmatites of southern California consist essentially of quartz and potash feldspar. They resemble granite in their mineral composition but, like the different varieties of granite, show mineral variations in themselves. With the similarity in mineral composition, there is necessarily a dose similarity in chemical composition, but in their other features the pegmatites are very different from the granites.

At some localities, particularly in North Carolina, the shape of the pegmatite masses is very irregular; at other places pegmatitic phases of granite occur which do not possess a distinctive shape and which imperceptibly merge into the surrounding normal granite. The pegmatites of the California field are very uniform in shape and possess the characteristic shape of a dike or vein whose thickness is very small in comparison with the other two dimensions. The proportion of pegmatite in comparison with the other rocks surrounding country rock is generally small, and at Pala is about 4 per cent of the total rock. The proportions ascertained are-for Stewart Hill, 3.7 per cent, for Pala Chief Hill, 2.9 per cent; and for Hiriart Hill, 5.3 per cent.

Pegmatites are considered to have been derived from other larger rock magmas by processes of differentiation, in which the effects of dissolved gases play a prominent part. The presence of a large body of granitic rock has been demonstrated for many occurrences of granitic pegmatites, though it has not always been shown that the two are genetically connected. Granitic rocks, as earlier stated, form the dominant igneous masses of the California field.

Irregular texture is one of the chief characteristics of pegmatites, as noted by Bastin[23] and by Warren and Palache[24]. Bastin regards the abrupt changes in texture and a coarser grain, at least in part, than is usual for the corresponding plutonic rock of a similar mineral composition, as among one of the essential features of a pegmatite. A finer grain is an additional distinctive characterization of pegmatites. Abrupt changes in texture are exceedingly well exemplified by the pegmatites described in this paper and are illustrated by the photographs of rock specimens

[23] Bastin, E.S. Origin of the pegmatites of Maine: Journal of Geology, vol. 18, p. 297, 1910.
[24] Warren C.H. and Palache, C. The pegmatites of the riebeckite-aegirite granite of Quincy, Mass., U.S.A.; their structure minerals, and origin. American Academy of Arts and Sciences Proceedings, vol. 47, p. 143, 1911.

shown in plates XI and XIII. Another phase of the abrupt changes in texture is the sudden beginning and ending of the masses of intergrown minerals, of which graphic granite forms the commonest example. The concentration in places of large masses of only one of the component minerals (quartz for example) furnishes an additional striking characteristic of pegmatites and also causes a great irregularity in the texture of the entire rock mass. The crystals in which are concentrated certain rare elements (lithium) in many cases are of a very different size to that of the minerals forming the matrix of the crystals. The deposition of the pegmatite minerals is not uniformly in the same order as that in a corresponding plutonic rock mass of similar mineralogical and chemical composition. This would in itself tend to give the rock an irregular texture.

Zonal arrangements are well developed in many pegmatites and are strikingly prominent in those of the area under discussion. These zonal features are partly shown diagrammatically in the figures illustrating the various types of pegmatites and also, in part, in the photographs of the pegmatite dikes (see especially Plates X and XI).

Large cavities or pockets are not a necessarily distinctive feature of pegmatites, for they are absent in many occurrences, as for example, in those of North Carolina, Colorado, and South Dakota. Neither is the absence of such cavities correlated with the presence or absence of the so-called rare elements, such as phosphorus, fluorine, lithium, and the rare-earths; for the North Carolina pegmatites contain apatite and rare-earth minerals; the Colorado pegmatites contain lepidolite and lithium tourmaline; and those of South Dakota contain amblygonite, spodumene, and cassiterite.

The presence in quantity of elements occurring only as traces in ordinary rocks constitutes a very distinctive feature of some pegmatites, but is by no means a distinguishing feature of all of them. For example, Bastin[25] says of the Maine pegmatites:

"The pegmatites … in which unusual minerals were present in especial abundance … constitute, however, only an exceedingly small proportion of the pegmatite in any district. … Certain deposits showing typical pegmatitic textures … have been worked for their feldspar for years with the discovery of few if any of the rarer minerals."

The California pegmatites are no exception to the statement that these rare elements are found in only a small percentage of the total number of pegmatites in a given area, for at Pala where the pegmatites were best exposed these rare elements occur in not more than 10 per cent of all the pegmatites exposed. The rare-elements found in the California pegmatites are: Boron, fluorine, phosphorus, lithium, beryllium, manganese, bismuth, tin, antimony, columbium, and tantalum.

In the gem tourmaline field of southern California, the pegmatite dikes dip to the west at from 15 to 35°. Their strike in general lies between a north to south and a northwest to southeast direction. The strike is therefore parallel to the physiographic features of California, such as the coast line, the mountain chains, and the valleys. This parallelism at once suggests that the fissures now filled by pegmatite were caused by tectonic movements related perhaps to the various oscillations that the western part of California has undergone. Most of the dikes have a thickness of between 20 inches and 20 feet, but the variation in thickness is considerable-from less than an inch to slightly more than 50 feet. The exposed outcrops extend from a few feet to several thousand feet.

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[25] Bastin, E.S., Geology of the pegmatites and associated rocks of Maine: U.S. Geol. Survey Bull. 445, p. 29, 1911.

The pegmatite dikes are very numerous and seem to be somewhat concentrated in certain areas. Where the general topographic features of a region are nearly the same and where there are numerous small dikes, their outcrops from a striking series of parallel lines. The white or light grey of the pegmatite contrasts strongly with the dark red soil of the decomposed gabbro and the nearly black color of the fresher gabbro.

The observed terminations of these pegmatite dikes are very abrupt. The constant thickness of the dike, which has extended for perhaps hundreds of feet, suddenly changes and in a very short distance the dike tapers to a point and pinches out. A prospect on Stewart Hill shows (fig. 3) a bulging before the final disappearance of the pegmatite.

Figure 3 Termination of pegmatite dike with a slight bulging near its end. Prospect No. 39, Stewart Hilt, Pala.

At another exposed termination the dike forked into three narrow arms, which pinched out in a short distance (fig. 4).

Figure 4 Termination of pegmatite dike, with forking. Hiriart Hill, Pala. (N.B. 2. p. 35.).

Two localities having numerous parallel pegmatite dikes are shown in Plate III. A shows the eastern side of the southern spur of Pala Chief Hill, lying between Stewart Hill and Hiriart Hill, at Pala. The photograph was taken from Hiriart Hill. There are at least seven well defined dikes on this side of the hill, all of them very nearly parallel. B is a view near Rincon, a short distance north of the Mack mine. The dikes are very numerous here and strikingly parallel. The miniature ridges have been developed with a pegmatite ledge as a backbone.

Many of the outcrops of the larger pegmatite dikes are traceable as a nearly straight line for a considerable distance, as the dike exposed on the east side of Stewart Hill (Pl. XV, page). In detail, however, the outcrop is in most places broken and irregular. Plate IV, A, shows a close view of the outcrop of the Tourmaline Queen dike on Stewart Hill, Pala, whereby its irregularity can be readily seen. The upper and lower surfaces of the dikes are strikingly smooth and even. Plate IV, B, shows the exposed upper surfaces of a dike near Rincon, similar to those shown in Plate III, B. The present exposed surface is somewhat rough from the effects of atmospheric agencies, but the general plainness of the surface can still be seen. Compare also Plate XXI, B, facing page

Summary of types.

For convenience of classification, the pegmatite dikes of the southern California gem tourmaline field are divided into three types, the homogeneous type, the symmetrical type, and the unsymmetrical type.

The first or homogeneous type is the common pegmatite, alike throughout in both texture and composition. Quartz and feldspar are the principal minerals, small quantities of mica, garnet, and black tourmaline being scattered through all parts of the dike. No lithium or gem minerals have been found in the dikes of the homogeneous type and cavities or pockets were not observed.

The second or symmetrical type is given that name because of the similarity of the upper and the lower parts of the pegmatite dike, which is divided by a central band or middle part of very coarse texture, having many cavities, and containing the lithium

and other rare-elements previously mentioned. The upper and the lower parts are similar to the homogeneous type of dike. The middle part is not continuous throughout the entire dike, but pinches out and disappears where the upper and the lower parts of the dike come together. The structural relations of the symmetrical type of pegmatite are shown in figure 5.

Figure 5 Sketch of structure of the symmetrical type of pegmatite dike.

Figure 6.-Exceptional phase of symmetrical type of pegmatite dike.

An exceptional phase of the symmetrical type is shown in figure 6. The symmetry of the dike is prominently developed, although the middle part containing its lithium minerals is absent, its place being taken by a fine-grained compact quartz-feldspar rock, in which are numerous wavy bands composed of minute blue-black tourmalines.

The third or unsymmetrical type contains the same coarse middle part with its lithium minerals, but the upper and lower parts of the dike differ markedly in both texture and composition. There are, therefore, three distinctive divisions in parts of the unsymmetrical type of pegmatite dike which, in the order of their supposed solidification, are called the lower part, the upper part, and the middle part. The upper and lower parts of the dike are of nearly the same thickness, although the lower part is generally the smaller. The upper boundary of the middle part is difficult to place as the middle and upper parts grade into each other. The lower boundary of the middle part is, on the contrary, very sharp and is well defined, being determined by the plane upper surface of the lower part. This upper surface of the lower part is well shown in Plate XVII, A. In this dike the material immediately above the lower part has been partly removed, well exposing the smooth upper surface of the banded rock. This pegmatite exposure is on Hiriart Hill, Pala, between the Katerina and the San Pedro mines.

This sharp contact of the middle part with the lower part forms a striking point of difference in comparison with the symmetrical pegmatites, in which the middle part grades on both sides into the surrounding rock. In some dikes the middle part of the unsymmetrical pegmatites has become firmly welded to the lower banded rock, as is shown in Plate XI, B. If stresses are applied where the two parts are welded together the dike will break at some place in the middle part, which is structurally weak on account of the numerous cavities and the general coarse texture. Such an instance is shown in Plate XVII, B, which illustrates a pegmatite exposure on Hiriart Hill at Pala. A diagrammatic sketch of a pegmatite dike of the unsymmetrical type is shown in figure 7.

Figure 7 Sketch of structure of pegmatite dike of the unsymmetrical type.

The lower part of these dikes is a fine to medium-grained rock consisting of quartz, albite, muscovite, and garnet, any one of which rarely exceeds a centimeter in diameter and generally is very much smaller. The texture of the lower part is finer than that of any other part of the dike. If garnets are very few, the rock has a granular structure; if garnets are abundant, they are sometimes scattered irregularly through the rock, but much more frequently they are concentrated in numerous wavy bands, which form a characteristic feature of these pegmatites that gives their lower half a very striking appearance (Pl. XI, B). Two dikes had these wavy bands composed of blue-black tourmalines mixed with a few garnets. The upper part of all the dikes of the unsymmetrical type is a coarse, graphic granite, similar to that of the pegmatites of the symmetrical type and illustrated in Plate VI, A. The middle part of the dikes is a coarse aggregate of quartz, feldspar, mica, and tourmaline, with the pay shoots of gem

minerals. It is identical in mineral composition with the middle part of the symmetrical type of pegmatites.

The lithium and gem minerals are confined in both second and third groups of pegmatites to a small portion of the dike. This small portion, averaging about 10 per cent of the whole, is a fairly well- defined streak, running irregularly through the center of the dike. In position and in character of material it does not very materially in the two groups of pegmatites. This streak, the part of the pegmatite prospected and mined and locally known as the "pay streak", is called the "middle part." In it are found the lithium and gem minerals, and the particular portion of the "middle part" containing these lithium and gem minerals is, in conformity with the usage of the United States Geological Survey, called the "pay shoot."26

An exceptional phase of the unsymmetrical type of pegmatite dikes is developed at a very few places where the middle part is absent, the upper graphic, granite and the lower banded rock being in contact (fig. 8). At two such occurrences the under surface of the upper part is covered with small cuplike depressions, which are described further on page

Figure 8 Exceptional phase of the unsymmetrical type of pegmatite dike

Homogeneous type.

The pegmatite dikes of the homogeneous type are very abundant in the granitic rocks of the region and they also occur in the gabbro, where they generally form narrow stringers associated with the larger pegmatite dikes of the other type types. Waring27 has mentioned a green hornblende granulite, a garnet granulite, and a biotite granulite as occurring in the granite. Many small dikes that contain only feldspar and quartz or predominant feldspar and mica but no tourmaline also cut the granite. Near Fallbrook a pegmatite about 20 inches wide, with strike from north to south and a dip of 80°E. has been prospected for gems. The dike consists of quartz, feldspar, and muscovite, with a little sillimanite near its center. A few quartz crystals enclosing black tourmalines were also obtained. The dike of prospect No. 72 on the eastern side of Stewart Hill consists of graphic granite as described and illustrated on page .

On the western side of Pala Chief Hill, near its base, are a number of homogeneous pegmatite dikes. One of these, 19 inches thick, is fine grained and has a slightly developed gneissoid structure. The prominent minerals are quartz, orthoclase, microcline, albite, and biotite. A small 8-inch dike is a coarse aggregate of quartz and microcline (not showing any graphic structure), including smaller amounts of garnet and biotite. The largest of several stringers is a medium to fine grained aggregate of quartz and feldspar, with much secondary biotite, though the other associated stringers are free from any biotite.

At Mesa Grande and also at numerous other localities small dikes, generally less than a foot thick, are abundant in both the gabbro and the granite. The dikes consist essentially of quartz and feldspar, with a little mica and an occasional imperfect crystal of garnet or black tourmaline.

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[26] The "pay shoot" is that part of a deposit that is rich enough to exploit.

[27] Waring, G. A., The pegmatite veins of Pala, San Diego County: American Geologist, vol. 35, pp. 356-369, 1905.

Symmetrical type.

Upper and lower parts.

The upper and the lower parts of the dikes of the symmetrical type are essentially similar and are therefore treated together. The structure of the dikes of the symmetrical type is shown in figure 5. Near the edges of the dike are generally a few wavy bands of minute bluish-black tourmalines or of reddish-brown garnets. The texture of the rock is in general very coarse, but the irregularity of the texture is likewise a noteworthy feature. There are occasionally small areas of fine-grained texture, and some of the minerals in the coarser-grained varieties are exceeding large in comparison with the size of the entire dike. The texture of the pegmatite at the edges of the dike is not at all places of much finer- grain than it is nearer the middle of the dike. The dike of prospect No. 44 on Stewart Hill, at Pala, however, shown very distinctly a fine-grained border at both top and bottom. The dike is 5 feet thick and the fine-grained border extends from both sides for about 3 inches. Lithium minerals are sparingly present in the center of the dike.

There is a general tendency for the minerals to become coarser the nearer they lie to the center of the dike. As a result, the coarsest part of the entire pegmatite, in which all the minerals reach their maximum size, is the central band or middle part in which the pay shoots containing lithium and gem minerals are found.

The rock forming the upper and the lower parts of the symmetrical type of pegmatites is composed either of quartz-feldspar with a graphic texture (graphic granite), or of a rock of similar composition but with a granular texture, or else of a mixture in varying proportions of both. Mineralogically the rocks of the upper and the lower parts of the symmetrical pegmatites are identical; texturally they are very different.

Most of the graphic granite is coarse-grained, although its texture varies at different localities. A fine-grained graphic granite is to be found in places in nearly all of the pegmatites of the region. Very coarse-grained rock, in which the feldspar or quartz grains exceed 5 centimeters in diameter, is also to be seen. The greater part of a single pegmatite is, however, fairly uniform in the size of the individual mineral constituents.

All of the graphic granites studied are composed of the three essential minerals microcline, albite, and quartz, which by their mutual relation form the graphic fabric of the rock. The accessory minerals are generally present in very subordinate quantity, but at a few places they are very abundant. They consist of muscovite, in small shreds or irregular flakes, rarely in imperfect crystals; black tourmaline, in large and small prismatic crystals; garnet, in well-developed crystals reaching a maximum diameter of about a centimeter, though usually much smaller; and, rarely, irregular, small shreds of biotite. Occasional minute idiomorphic crystals of orthoclase and of albite accompany the accessory minerals and lie embedded in the larger masses of intergrown quartz and feldspar.

A typical example of the graphic granite is illustrated in Plate VI, A. The specimen is from the Anita mine, in Riverside County, and a similar specimen was analyzed with the results given below. The weight of the rock carefully sampled was 380 grams.

Analysis and mineral composition of graphic granite from Anita mine, Riverside County, California.

W. T. Schaller, analyst.

Analysis.	
oxide	percent
SiO2	73.93
A12O3	13.77
Fe2O3	0.25
FeO	0.19
MnO	0.03
CA0	0.48
MgO	0.08
K20	9.16
Na20	2.00
Li20	trace
H20	0.16
C02	trace
Total	100.05

Mineral	Percent composition
Quartz	25.00
Microcline	54.00
Albite	17.00
Anorthite	2.00
Tourmaline	2.00
Sum total	100

The Tourmaline King mine, at Pala, and the Anita mine, in Riverside County, are in symmetrical pegmatites, which, with the exception of the middle part, consist essentially of graphic granite. The middle parts of the pegmatites in these mines contained a large quantity of valuable gem tourmaline and associated lithium minerals.

In many of these dikes the graphic texture is absent or very subordinate, and the rock then has a decided granular texture and is composed of a coarse aggregate of feldspar and quartz. In such dikes the accessory minerals are generally more abundant than in the graphic granite and at places almost equal either the feldspar or the quartz. Even where the graphic structure is nearly absent, the phases of the rock ·with a graphic fabric are by no means rare and in places are so abundant that the rock could as well be classed as graphic granite.

A sample from the Tourmaline Queen mine, at Pala, showed in thin section quartz, albite, and orthoclase, each with a diameter of several millimeters. The texture is granular, all the minerals being xenomorphic. Albite is more abundant than orthoclase and microcline is not present. A second thin section showed the granular rock composed of quartz, orthoclase, and albite, with a very little tourmaline and muscovite. A third section of a specimen rich in tourmaline and garnet showed practically no feldspar. All the minerals are large and the garnet and tourmaline are arranged in an imperfect intergrowth with the quartz.

A sample of granular pegmatite from Rincon showed in the hand specimen masses of feldspar and quartz more than a decimeter in maximum size. Muscovite plates a centimeter across the long, slender black tourmaline prisms a centimeter thick and en centimeters long are scattered throughout the rock. Garnet though, present is much less abundant than the other two accessory minerals. About half of the black tourmaline is altered to muscovite. An example of this rock is illustrated in Plate XXXIII, facing page . Observations under the microscope show the essential minerals to be quartz, orthoclase, and albite, with the accessory minerals present in small quantity. A specimen of this rock weighing 1,315 grams was crushed and sampled and then analyzed with the results shown below.

Analysis and mineral composition of pegmatite from Rincon, California.
W.T. Schaller, analyst.

Analysis.	
oxide	percent
SiO2	74.74
Al2O3	15.38
Fe2O3	-------
FeO	0.77
MnO	0.04
CaO	0.26
MgO	0.03
K2O	4.26
Na2O	4.20
H2O	0.58
Total	100.26

Mineral	Percent composition
Quartz	32.10
Muscovite	9.0
Orthoclase	18.9
Albite	36.00
Anorthite	1.00
Tourmaline	3.00
Garnet	1.00
Sum total	101.00

Although the main mass of some of these pegmatites is composed of the granular aggregate of quartz and feldspar, graphic granite is by no means rare, and usually forms small local masses, which at places may extend to a considerable distance. At the edges of these local masses the graphic granite loses its well-defined structure and imperceptibly merges into quartz-feldspar rock with a granular texture.

In some part of these dikes there are also bodies, extending for many feet, which consist essentially of but one mineral, of which quartz may be cited as an example. A fine-grained rock, some of which is marked with wavy bands, usually tourmaline, also occurs. As seen in thin section this fine- grained rock is composed essentially of albite and quartz, very little orthoclase, garnet, and tourmaline being present. The albite forms rectangular crystals much twinned and showing the irregular rounded border due to reabsorption. Their length averages from half a millimeter to 1millimeter, their thickness being one-half to one-third as much. The larger xenomorphic quartz masses have diameters of about 3 millimeters. The garnet and tourmaline crystals appear greatly corroded and in size are a little smaller than the albite. The rock is very similar to the nonbanded portion of the lower half of the second group pegmatites, as described on page.

The rock forming the granular aggregate represents therefore a conglomeration of at least four kinds of rock, which are present in varying proportions and which grade into one another. These are: (1) the coarse granular aggregate of quartz and feldspar, with accessory muscovite, tourmaline, and garnet; (2) graphic granite, composed of orthoclase, albite, and quartz; (3) large bodies composed of a single mineral; (4) fine-grained rock composed essentially of quartz and albite.

Examples of the rocks described, and which constitute the upper and lower parts of the symmetrical type of pegmatite dikes are shown in Plate VI. A is graphic granite similar to that found in many places. B is an intermediate phase of the graphic and the granular fabric. It is largely formed of graphic granite, though a careful inspection is needed to see the graphic texture, which is not nearly so apparent as in A. As the graphic texture becomes less prominent, black tourmaline, almost entirely absent in A, increases in quantity. C and D consist essentially of a granular aggregate of feldspar and quartz, with small but appreciable amounts of muscovite, black tourmaline, and garnet. Locally small masses are developed where the quartz and feldspar tend to form graphic granite, as in the center of C where such a mass can be seen lying between the large feldspar crystal on the left and the more granular aggregate to the right. The feldspar crystal is larger than any of the other components of the rock, and its cleavage surfaces measure over 5 centimeters in length.

Middle part.

The boundaries of the middle part of the pegmatites are difficult to define as the gradations into the normal pegmatite of the upper and the lower parts are gradual on all sides. In many places the middle part is distinguished only by the presence of one or more lithium minerals, but in most places the character of the minerals is very different from that found in any other part of the dike. The varying size of the middle part is one of its marked features. Naturally varying with the size of the entire pegmatite dike, it also shows great irregularity in the same dike and even at points close together. At a certain place in a dike of uniform thickness, the middle part is very small and thin; at other places it disappears completely; only a few feet away it bulges out into a large mass; and it generally keeps this variant character throughout the entire extent of the dike. Its irregularity in size and shape are in contrast to the middle part of the second group pegmatites, wherein both the size and shape are more constant.

The minerals forming the bulk of the middle part are the same as those found throughout the entire dike, namely, quartz, feldspar, and mica; but these common minerals have a different appearance from those seen in the other parts of the pegmatite. They are generally developed in large, well-formed crystals such as shown in Plate VII, B, wherein the tourmaline, quartz, and albite look very different from the tourmaline, quartz, and albite shown in the rock specimens of the upper and lower parts in Plate VII. In addition to the large size is the development of well-formed crystals bounded by their natural crystal faces. These well-developed crystal faces naturally suggests the presence of cavities. As a matter of fact, cavities are very abundant in the middle part and form one of its chief distinctions. Plate VII, A, shows such a cavity partly filled with well-developed tourmaline crystals.

Quartz occurs abundantly in large massive bodies and also, in quantity, in short, doubly terminated crystals, either of perfect clearness, or else brown, smoky yellow, pink, white, or in other shades. The crystals are of very different sizes, some being almost microscopic and many others more than a foot in length, (Plates I and VII, B.) Potash feldspar is found in large, cleavable masses, fairly pure and free from quartz, as well as in large, well-defined crystals, usually opaque and grey in color (Pl. XXVII, C, p.). Rarely they are nearly white and translucent and still more rarely almost transparent pieces are obtainable. Muscovite occurs in groups of wedge-shaped crystals and in small, scaly masses. The groups of wedge-shaped crystals, are rarely found in the pegmatite outside of the middle part. Albite assumes the characteristic tabular or platy form of the so-called cleavelandite (Pl. XXVIII, A, p.   ).   Black tourmaline and garnet have almost entirely disappeared. On the other hand lithium minerals, such as lepidolite, pink and green tourmaline, and, less prominently, spodumene, and amblygonite, are present in abundance.

Where these last named minerals, especially the tourmaline and spodumene of gem value, are found, the middle part becomes .a true pay-shoot.28 As gem minerals (transparent tourmaline, spodumene, beryl, and garnet) are the incentive to the exploitation in the California tourmaline field, and description of the pay shoot is that of these gem minerals, their occurrence, and their association. The description of the minerals themselves is given in Part IV of this report; but their mode of occurrence and their general appearance is briefly given here. The richness of the pay shoot varies considerably at different places. Certain parts are so rich that thousands of dollars

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28 The pay-shoot has been defined as that part of a deposit which is rich enough to exploit

worth of gem minerals are taken out in a few minutes; other parts are mined day after day with hardly a gem crystal to be seen. Lithium minerals of no gem value are likewise very irregular in their distribution being at places (as in the Stewart mine, at Pala) concentrated in bodies many feet thick, whereas in other parts of the same dike, only a few isolated grains are scattered through the rock. The map of the Anita mine, in Riverside County, given on page (x), gives an idea of the irregularity of the pay shoot deposit.

The minerals of the pay shoot which are of value-the gems and the large bodies of lithium ore-are found in four distinct modes of occurrence. These are (1) in large masses of pure or nearly pure "ore", (2) as individual gem crystals firmly imbedded in the solid quartz or feldspar. (3) as crystals lining pockets or cavities in the rock, and (4) as constituents of a friable, decomposed rock consisting of gem crystals, quartz, mica, and altered feldspar.

(1). The large masses of nearly pure lithium minerals have been found only at Pala and consist of local concentrations of either lepidolite or amblygonite (Plate page xx). They become very large at places, the largest ore mass in the Stewart mine having a maximum dimension of about 200 feet. Their description will not be repeated here as it is given under the section describing the mines.

{2). Where the gem crystals are firmly imbedded in the solid quartz or feldspar, they are termed "frozen" by the miners. Such occurrences are generally of little value, as the gem stones are almost everywhere considerably checked or cracked, or, if clear, will become more or less shattered before they can be removed from the firm matrix. Where the matrix was originally largely feldspar, but now altered to clay, an area of loose friable material, called a pocket, forms the forth mode of occurrence.

(3). A third form of occurrence is where the minerals form a coating or lining on the walls of a cavity, many of the crystals, especially quartz and tourmaline, projecting into the open space. In several such pockets the entire inside of the cavity was lined with these drusy coatings. It is believed that most of the cavities that do not now show any drusy coating have simply lost it through shattering and decomposition of the feldspar rock to which it was at first attached. Most of these cavities have undergone considerable alteration, so that the drusy linings of the walls with their projecting crystals have fallen to the bottom of the cavity. Extraneous clay has filtered in, and now the cavity consists of a confused mass of perfect crystals, more or less crystalline material with adhering pegmatite rock, and abundant clay. Many of these areas of so-called "rotten rock" form very valuable pockets containing abundant gems. The contents of almost all the pockets have become covered with brown clay so that all the material is first sun dried, when much of the clay falls off, and then washed, after which the gem minerals of value can be easily recognized and picked out. {See Pl. IX, p.) Two small but complete cavities were found in the pegmatite at the Himalaya mine at Mesa Grande. The largest cavity measured about 2 inches by 2 inches by 1 inch, and the second was slightly smaller. Both cavities retained their drusy lining and projecting crystals which were carefully removed and their composition determined. The surrounding pegmatite was very little altered, but considerable brown day had filtered into the cavities through small crevices. The contents of the larger cavity, as collected, weighed 113 grams, of the smaller cavity 97 grams. The material was separated according to size ·with the following results. More than half of the contents of both pockets consists of material larger than 10 mesh. The finer material seemed to contain more clay than the other grades but otherwise no important difference was detected in their mineral composition of the other grades.

Percentage by weight of different sizes of contents

of cavities in pegmatite at Mesa Grande.

Size.	First cavity.	Second cavity.
Finer than 40 mesh	18	9
Coarser than 40 mesh but finer than 20 mesh	13	10
Coarser than 20 mesh but finer	14	23
than 10 mesh	14	23
Coarser than 10 mesh	55	58
	100	100

The material coarser than 10 mesh was separated by hand into its mineral constituents, with results as follows:

Percentage by weight of minerals in cavities in pegmatite at Mesa Grande.

Mineral.	As collected.		Clay and gabbro deducted.	
	First cavity.	Second cavity	First cavity.	Second cavity.
Brown clay	7	3	--	--
Gabbro fragments	4	--	--	--
Elbaite (lithium) tourmaline	52	36	60	41
Albite	11	23	12	28
Orthoclase	16	17	18	19
Lepidolite	4	9	4	10
Quartz	4	2	4	2
Stibiotantalite	2	--	2	--
	100	100	100	100

Of the elbaite or lithium tourmaline 97 per cent was pink in the first cavity and 90 per cent in the second cavity, the remaining tourmaline being mostly greenish, though some was yellowish or without color. The high percentage of pink tourmaline and the very low percentage of quartz are rather unexpected. These two cavities are the only

one whose contents could be quantitatively measured. But the mineral composition of some other pockets can at least be estimated. If the specimen shown in the frontispiece be considered as typical of the entire cavity from which it came, then the contents of that cavity was about 50 per cent pink tourmaline, 25 per cent quartz, and 25 per cent albite. On the same basis the cavity from which the specimen shown in Plate xyz came, had as its contents, quartz 50 per cent, green tourmaline 25 per cent, orthoclase 20 per cent, and mica 5 per cent. The cavity shown in Plate VIII, page xx, contained 100 per cent tourmaline (elbaite). On the other band, cavities free from tourmalines and containing essentially nothing but quartz, feldspar, and mica are very abundant. The cavity from which the group of lepidolite crystals shown in Plate XXXVII, page , was obtained contained practically nothing but lepidolite. Cavities were seen at Pala in which quartz was the only mineral. The small cavities in massive albite (Pl. VIII, page) from Ramona are lined throughout by albite, from which project crystals of green tourmaline, lepidolite, and topaz in approximately equal proportions. Muscovite, quartz, and orthoclase are practically absent from these cavities. A summary of the estimated contents of the cavities just described is given below and serves to show how extremely variant is their mineral composition.

Estimated mineral composition of the contents of cavities
in the middle part of the California lithium-pegmatites

Mineral	Percentage of mineral								
Elbaite (lithium tourmaline)	0	100	--	--	50	25	11	60	41
Quartz	40	---	--	100	25	50	--	4	2
Lepidolite	0	---	100	--	--	--	11	4	10
Muscovite	10	--	--	--	--	5	5	--	--
Albite	10	--	--	--	25	--	67	12	28
Orthoclase	40	--	--	--	--	20	--	18	19
Topaz	--	--	--	--	--	--	11	--	--
Stibiotantalite	--	--	--	--	--	--	--	--	--

Several specimens illustrating the third mode of occurrence of the gem minerals in the pay shoot are shown. Plate VIII C, shows (natural size) a group of green tourmalines and quartz and muscovite crystals. The lower part of the specimen is the firm rock of the first-group pegmatite, and especially to be noted is the remarkable change in texture between the solid pegmatite rock and the crystals projecting into part of a former cavity. The specimen belongs to the collection of the late A.F. Holden. Another peculiar feature shown by this illustration is the association of the minerals: quartz, green tourmaline, and muscovite. The common association of these cavities is red and green tourmaline, quartz, lepidolite, albite, and potash feldspar. Plate VII A, shows (natural size) a cavity lined completely with colored tourmalines, mostly pink. The specimen was covered before photographing with a dull coating of ammonium chloride to avoid the bright reflections from the brilliant faces of the tourmaline crystals. The specimen also shows the diversity of size of the same mineral under apparently

similar conditions. A group of small tourmalines (shown in the upper right hand corner) includes a single crystal almost as thick as the entire group. The main mass of the specimen consists of white tourmaline and in the rear of the specimen shown in this plate is a small cavity lined with projecting crystals, a photograph of which, enlarged four times is shown in Plate VIII A. A portion of this cavity, enlarged many times, would show a structure such as is actually shown (natural size) in Plate 1 as well as in many other plates.

(4). The last mode of occurrence is by far the most abundant and is the one from which the best and most valuable gems have been taken. It consists simply of an irregular mass of decomposed rock carrying gem minerals, and it may have resulted from an original occurrence of mode 2, wherein the firm matrix was potash feldspar now changed to a soft and crumbling clay, or it may have been formed by the collapse of a cavity such as described under mode (3). The gems are found as loose individuals covered with brown clay and associated with unattached quartz, feldspar , and mica. This is the most frequent mode of occurrence, and the entire mass of loose minerals, mixed with the clay, constitutes the "pocket matter", the "pockets" themselves being the irregular spaces occupied by this loose mixture of minerals. In places the pocket matter is dry and loose; in other places it is consolidated into a moist, clayey mass from which the gem stones have to be washed. The clay in these pockets is usually brown in color and probably most of it comes from the overlying altered gabbro, as there is no mineral in the pockets themselves which contains sufficient iron to stain the clay brown. The decomposed orthoclase has contributed somewhat to the clay, which in still smaller proportion was derived from the altered spodumene and pink tourmaline. This clay, however, is usually differentiated from the ordinary brown clay by its pinkish color.

When the presence of gem minerals is suspected in the decomposed rock, the pocket matter is carefully removed from the ledge, brought to the surface, spread out in the sunlight, and allowed to dry. The dried clay crumbles and falls as a loose powder off the unaltered minerals. The remaining matter is then thrown against a coarse screen, which catches only the larger pieces, freed from most of the obscuring clay. The tourmalines and what is suspected to be tourmaline are then picked out by hand and placed in water. See illustration, Plate IX, page   . After being allowed to soak, the stones are washed clean, and then the gem tourmalines are readily detected. The tourmalines can easily be detected on the screen by an experienced operator, the general form and shape being usually sufficient to identify the gems, whose red or pink color also often shows through the clay.

Where water is abundant, the pocket matter is not first sun dried, but is at once placed in a revolving barrel partly filled with water. The obscuring brown clay is easily removed and the gem mineral is picked out.

An examination of the pocket matter at the Tourmaline King mine at Pala, shows it to consist of elbaite (mostly pink) 39 per cent, quartz 34 per cent, orthoclase 12 per cent, lepidolite 7 per cent, muscovite 5 per cent, albite 3 per cent.

The minerals in the pay shoots-irrespective of whether they are of gem value or not-differ in certain peculiarities of occurrence and form from those found in the upper and the lower parts of the pegmatite dikes.

Their frequent occurrence in cavities has already been mentioned. The cavities are either in the pegmatite rock (Plate VIII, C) or they are in pure mineral unmixed of some kind. Plate VIII, A, illustrates such a cavity in a solid mass of white tourmaline. The crystals projecting into the cavity are also white tourmalines but, as the illustration well shows, are much larger. The agencies producing the cavities tend to develop large crystals. Plate VIII, B, shows a specimen of albite containing several cavities, the walls

of which are lined by a delicate lacework of albite crystals accompanied by a few crystals of green tourmaline, lepidolite, topaz, and stibiotantalite. These cavernous albites are especially well developed at Ramona.

Radiated groups of crystals are well developed at some places, and a fine example is represented in Plate VIII, F, (enlarged two times). The three minerals tourmaline (T), lepidolite (L) and albite (A) form well-defined radiating units of which the lepidolite is especially interesting. The radiating area consists of well-developed tabular crystals arranged end on end in line. These lines are nearly parallel and yet sufficiently divergent to form the radiating structure. Scattered promiscuously over these three radiating minerals are isolated crystals of topaz, formed by a later deposition.

Many of the crystals from the pay shoot are well developed crystallographically and bounded by plane and brilliant surfaces. Yet it is characteristic that many of these minerals are remarkably etched and part dissolved. Plate VIII, D, shows (natural size) a topaz crystal considerably dissolved or eaten into on one side. Plate VIII, E, shows a crystal of spodumene-the gem variety kunzite-which has been remarkably etched and partly dissolved and yet has retained its perfect transparency. So too many of the other minerals have been attacked chemically and in many cases partly dissolved or altered.

Unsymmetrical type

Lower Part.

The lower part of the pegmatite dikes is a fine-grained to medium-grained compact rock composed essentially of quartz, albite, muscovite, and garnet. In the hand specimen it has an even granular texture, with an occasional porphyritic garnet, black tourmaline, or muscovite. The individual minerals are small, seldom exceeding a centimeter in diameter.

Some of these dikes do not show any banding, the results in part of the absence of any large number of dark-colored garnets or tourmalines. A study of several thin sections of different occurrences of such nonbanded rocks has shown that any banded arrangement of any of the constituent minerals is very rare. The rock resembles that sh0\\-11 in Plate XIII, B, though garnets are much scarcer than in the specimen illustrated. Studies of thin sections of specimens from the Tourmaline Queen, Stewart, and Pala Chief mines has shown that the chief mineral constituents are albite, quartz, and muscovite, the rock being very similar in composition to that shown in Plate XI, B.

The typical phase of the lower part of the unsymmetrical pegmatite is where the bands extend through the lower part of the dike. A view of such an occurrence is shown in Plate X, A, and a more detailed "View of the banded portion alone in Plate XI, C. Each of these photographs shows a vertical extent of about 5 feet. The accompanying smaller view, Plate XI, A, shows a dike in which the banding is only partly developed in the lower portion. As shown in Plate XI, C, the bands consist of either gentle curves, which for a small distance appear as straight lines, or they are very irregular and crinkled. Phases of the rock illustrating these two kinds of banding are shown natural size in Plate XII.

The rock is light-colored and medium-grained, and the garnets, with an occasional black tourmaline, are the only dark-colored minerals in it. All the minerals are arranged in more or less well-defined layers, as is well shown on a polished surface. By slightly etching a polished portion of the rock shown in Plate XII, A, the

banded arrangement of the constituent minerals is very well brought out and is diagrammatically shown in figure 9.

Figure 9 Pollshed and etched surface of banded rock, showing the banded arrangement of the constituent minerals.

In thin sections it is seen that the rock has a hypidiomorphic granular fabric, in places policlinic. The garnets and the tourmalines are developed idiomorphically, and the garnets are arranged in bands parallel to the dip of the pegmatite dike. The bands are of unequal thickness and are also very unequally spaced. In some of the narrow bands the garnets are huddled together in small groups separated by clear spaces free from any garnet, as shown in figure 10.

Figure 10 Small bands of garnets huddled together in groups.

Many of the garnets are sharply bounded by brilliant and plane surfaces, which in all observed cases consist of faces of the rhombic dodecahedron d (110). A large but variant number of the crystals, however, have the appearance of having been part resorbed. Such a crystal is shown in figure 11.
.
Figure 11 Sketch of apparently resorbed garnet crystal in banded rock

No relation could be observed between the resorbed crystals and their position with respect to the bands. The garnets are pale brown in thin section, isotropic, seldom cracked or fissured, and almost never altered. Only two crystals were seen that were partly altered to a micaceous mineral, probably muscovite. These garnets are composed of equal amounts of almandite and spessartite. The resorbed crystals and those bounded by plane crystal faces are indiscriminately mixed together, as the sketch in figure 12 shows.

Figure 12.-Sketch of garnet crystals In banded pegmatite. Shows resorbed crystal and sharply defined idiomorphic crystals mixed together.

The tourmaline, black in the hand specimen but deep blue in this section, is not abundant except in those phases of rock in which it takes the place of garnet and is arranged in parallel bands. The striking feature of these tourmalines is their zonal development of color intensity. The strong pleochroism is blue and purple. Some of the tourmalines, like the garnets, have been partly resorbed, and many tourmalines enclose numerous garnets.

The muscovite and albite are hypidiomorphic to idiomorphic and are not as perfectly arranged in bands as the garnets. These are, however, well-defined bands in which muscovite is abundant, whereas in other bands it is nearly absent. Albite, too, forms almost the only constituent of certain bands and in others it is very sparingly present. Muscovite occurs in crystals generally partly resorbed and also in more perfectly developed crystals. Typical forms of the muscovite are shown in figure 13.

Figure 13 Typical forms of muscovite In the banded rock.

Figure 14 Typical forms of albite crystals in the banded rock; a, crystals partly resorbed, Katerina mine, Hiriart Hill; b, crystals much more resorbed, San Pedro mine, Hiriart Hill.

The albite is very abundant as rectangular prisms and stout laths many of them more or less resorbed. They all show the albite twinning, whereas the pericline twinning was very seldom seen. Figure 14 shows some sketches of typical albite crystals. Orthoclase is very sparingly present in irregular masses, with occasional Carlsbad twinning.

Quartz forms only allotriomorphic masses, many of which are much larger than those composed of garnet, muscovite, or albite. Nowhere were any indications of crystal boundaries seen in the quartz. It often has a poikilitic structure enclosing crystals of muscovite, albite, or garnet.

An analysis was made of a sample of the lower banded rock from the Katerina mine on Hiriart Hill. This banded rock has a thickness of 15 feet at this mine and is a typical example of the banded lower part of these pegmatites. A sample of rock weighting 502 grams and identical with the one shown in Plate XII, A, was crushed and carefully sampled. The analysis and mineral composition calculated there from are as follows:

Analysis and mineral composition of banded
Lower part of pegmatite, Katerina mine, Hiriart Hill, Pala.
W.T. Schaller, analyst

Analysis.	
oxide	percent
SiO_2	74.29
Al_2O_3	14.93
Fe_2O_3	0.77
FeO	0.79
MnO	0.89
CaO	0.41
MgO	0.00
K_2O	2.38
Na_2O	4.67
H_2O	0.56
Total	99.69

Mineral	Percent composition
Quartz	37.00
Orthoclase	3.00
Albite	40.00
Anorthite	2.00
Muscovite	14.00
Garnet	4.00
Sum total	100.00

The partly banded rock of the lower part of the dikes shows a fine-grained to medium-grained rock, in which the bands extend one quarter to one half the way across the entire extent. These bands are generally at the top of the lower part and are similar in character to those just described. In another phase of the partly banded division, shown in Plate XI, C. the bands are present in quantity at the top of the lower part and also at the bottom of the dike. Between them, in a position corresponding to the center of the lower part of the dike, is a fine-grained rock free from any banding. This phase is well developed at one of the open cuts of the San Diego mine, at Mesa Grande. Here the entire pegmatite, about 2 feet thick, is well exposed and consists of a solid rock mass, just above the center of which are found lithium, tourmaline, and lepidolite. The characteristic middle part, soft and friable and full of cavities, is absent, and the lithium and gem minerals are firmly embedded, or "frozen", as the miners term them, in the solid rock. Just below the middle part of the dike is a narrow series of bands (Pl. XIII, A). Study of thin sections showed that this banded portion was similar in structure and composition to the banded rock of the first division. Below this banded series is either a fine-grained nonbanded rock (Pl. XIII, B.) or a fine-grained graphic granite. At the bottom of the dike is a narrow layer of rock much coarser than the rest

of the lower half and the extreme lower edge (one millimeters thick) is very fine-grained. The structure of this dike (No. 2 of the San Diego mine, Mesa Grande) as seen in its outcrop in the big open cut shown in figure 27, page   , is as follows:

Chief division of dike N. 2, San Diego mine, Mesa Grande,
with approximate thickness.

Divisions	Thickness in centimeters	Average thickness in centimeters
Upper Part, Coarse-grained, graphic granite and granular feldspar quartz rock	25 to 37	31
Middle part, lithium minerals	7 to 20	14
Lower part, banded	7 to 9	8
Not banded, either a fine-grained garnet rock or a fine grained graphic granite	15 to 20	18
Bottom of ledge, coarse in texture	2 to 5	4

The banded portion of the lower part of the dike consists of numerous small bands, more or less wavy and formed of different combinations of the same minerals that form the rest .of the rock. The principal criterion for the bands is the variously colored minerals, the garnets being brown, the tourmalines black, the muscovite pale greenish, and the quartz and feldspar white. The banded part (shown in Pl. XI.A), about 7 to 9 centimeters thick consists, in descending order, of the following bands described by their dominating minerals. All the minerals, however, occur in every layer but sometimes only in very small quantity.

Layers in banded rock	Thickness in millimeters
1. Fine-grained quartz and feldspar	4
2. Fine-grained quartz and feldspar and tourmaline	2
3. Coarse-grained quartz and feldspar	10
4. Coarse-grained garnets	3
5. Coarse-grained quartz, feldspar, and muscovite	15
6. Wavy bands of garnets in fine-grained quartz and feldspar	15-20
7. Fine-grained quartz and feldspar	10
8. Garnets in fine-grained quartz and feldspar	--
9. Coarse-grained quartz and feldspar	15
10 Fine-grained quartz and feldspar	5

In several of the layers the crystals are arranged more or less vertically, so that their greatest length is normal to the direction of the bands. Black tourmalines from the upper part of the dike, which contains them in abundance, occasionally project through layers Nos. 1, 2, and 3.

The dike below this banded part is formed either of a fine-grained garnet rock, not banded, or else of a fine-grained graphic granite. As seen in hand specimens, (Pl. XIII, B) the garnet rock is a fine-grained, crystalline aggregate of quartz, albite; garnet, muscovite, and a little tourmaline. The diameter of the various minerals is very uniform and is about half a millimeter. The albite and quartz are the most abundant, though both garnets and muscovite are present in quantity. The tourmalines occur very sparingly. Under the microscope a little orthoclase and microcline are apparent. The minerals comprising the rock are similar in appearance to those described in the banded garnet rock with the exception of the garnets. Nearly all of these have a corroded contour, sharply defined idiomorphic crystals being very scarce.

The other variety of rock is a fine to medium grained graphic granite, containing, in places, some muscovite and also large blotches of tourmalines and, very rarely, a few small garnets. Under the microscope, the fine graphic granite is seen to consist of microcline, quartz, albite, tourmaline, and muscovite. The microcline is more abundant than the quartz and albite. The gridiron structure of the microcline is but faintly developed in some places, although well-developed areas of cross grating occur in bunches throughout the entire section. In the blotches of tourmaline, orthoclase and microcline are almost entirely absent, the principal minerals being quartz and albite, with some muscovite. The extreme bottom of the ledge is usually a medium to coarse-grained aggregate of quartz and feldspar, sometimes forming graphic granite, through which black tourmalines are promiscuously scattered or, as smaller crystals, they form one or two wavy bands.

Upper part.

The coarse-grained upper part of these pegmatites is fairly uniform throughout and consists chiefly of graphic granite (Pl. VI, A). The component minerals are microcline, albite, and quartz. Other minerals are present almost everywhere, generally in subordinate quantity, though occasionally they become very abundant. Muscovite in small shreds or irregular flakes or large wedge-shaped books, black tourmaline in large and small prismatic crystals, and garnets in well developed crystals a centimeter in diameter can be detected almost everywhere.

The extreme upper portion nearest to the gabbro or country rock consists for several inches of either a coarse-grained granular aggregate of quartz and feldspar or of a finer-grained graphic granite, with characteristically large elongated flakes of biotite arranged nearly vertically and normal to the contact plane. The biotite is frequently altered to some variety of chlorite.

The graphic granite, by far the largest portion of the upper part of the pegmatites, varies considerably in texture at different places, being rarely very fine-grained, and passing through various grades to an exceedingly coarse grain, in which both the quartz and the feldspar form individuals many centimeters in length.

A sample of the graphic granite from the Katerina mine, where it is typically developed for a thickness of about 15 feet, was analyzed with the results shown below. The sample selected was a medium-grained rock weighing 452 grams, which was crushed and carefully sampled. The analysis yielded the following results:

Analysis and calculated mineral composition of graphic granite of upper part of ledge, Katerina mine, Hiriart Hill, Pala.

W. T. Schaller, analyst

Oxide Analysis		Mineral Composition	
SiO_2	72.80	Microcline	47
Al_2O_3	15.07	Albite	29
Fe_2O_3	0.26	Quartz	22
FeO	0.21	Muscovite	1
MnO	trace	Tourmaline	1
CaO	none		100
MgO	none		
K_2O	7.92		
Na_2O	3.35		
H_2O	0.30		
	99.91		

In this graphic granite three distinct modes of occurrence of the same minerals maybe noted. One mode appears as irregular masses that vary greatly in size, some being several feet across, and that consist of a granular aggregate of quartz, feldspar, and mica, without any trace of the graphic structure. This phase is identical in kind with that described as forming the rock of coarse granular texture of the pegmatites of the first group. Potash feldspar is the predominating mineral, but albite is present in quantity, and crystals of black tourmaline and light-brown garnets are also present. A second mode appears as masses or nests, generally only a few inches across, of intergrowths of quartz and one of the other minerals of the dike. These of quartz and microcline, of quartz and garnet, of quartz and black tourmaline, and of quartz and muscovite often stand out in bold relief. A third mode appears as small veins of material coarser than the surrounding rock that usually start from the middle part of the ledge and run irregularly upward through the graphic granite or form bands parallel to the dip of the entire dike (illustrated in Pl. XI,AO and are entirely enclosed in the graphic granite. Large individuals of quartz, feldspar, and muscovite form these small pegmatite veins, which are similar to the middle part. The lower side of this upper part loses its graphic fabric and becomes hypidiomorphic to idiomorphic. The constituent minerals are very large and in many places develop definite crystal faces. This part of the dike merges gradually into the middle part.

Middle part.

The middle part of the unsymmetrical type of pegmatites is fairly well defined and has a fairly constant thickness. Its upper portion grades insensibly into the graphic granite lying above and no exact boundary line can be determined. Its lowest portion rests directly on the smooth surface of the lower banded rock and the boundary line is very sharp and well defined (Pl. X, A). Below the graphic granite the component minerals are very large. The quartz, the potash feldspar, the black tourmalines, and

the sheets of muscovite show a pronounced tendency to form euhedral crystals. The large black tourmalines, arranged more or less vertically and at many places in a slightly radiating position, are very characteristic of this part of the dike, and where a number of them point downward to a single spot, are believed by the miners to be indicative of the presence of a "pocket" of gem stones below.

Beneath the zone of large black tourmalines is the streak of coarsely crystallized material, composed of large crystals of quartz, feldspar, and muscovite, together with smaller crystals and crystalline masses of albite, lepidolite, and gem tourmaline, in many places concentrated in the pockets or cavities.

The description of the modes of occurrence of the minerals of the middle part and especially of the gem and lithium minerals of the pay shoot as given for the symmetrical type of pegmatites applies equally well here and need, therefore, not be repeated.

Several variations from the characteristic phase of the middle part were noted as follows: The middle part is a sharply defined aggregate of coarsely crystallized quartz, feldspar, and mica, in which lithium and gem minerals are absent. Plate XI, A, shows such an occurrence at the San Pedro mine on Hiriart Hill.

The middle part consists of massive quartz. Only one such an occurrence was seen, and the photograph of it is reproduced in Plate XVII, A, Hiriart Hill.

The middle part consists of massive quartz containing isolated crystals of red tourmaline, muscovite, and lepidolite, all "frozen" together into a firm rock. Fairly abundant in the old surface workings of the San Diego mine at Mesa Grande.

The middle part consists of several alternations of the upper graphic granite and the lower banded rock. Observed only once in Prospect No. 76 on Stewart Hill and sketched in figure 23 on page

The middle part consists of alternating layers of quartz and feldspar. Observed in Prospect No. 35 on Stewart Hill and sketched in figure 20 on page

Paragenesis of pegmatite minerals

In a recent paper, Rogers[29] has discussed the use of the term paragenesis and, after defining it as "the association of minerals with special reference to their occurrence and origin", has suggested that the term be used to include occurrence, association, order of succession, and origin. Seventeen types of mineral occurrences are listed by Rogers, which seem to cover the field so well that they are here repeated.

Occurrences of minerals after Rogers (1910).

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[29] Rogers, A.F., The paragenesis of minerals: Econ. Geology, vol. 7, p. 638, 1912.

1	Igneous rocks.	10	Deep veins.
2	Meteorites.	11	Shallow veins.
3	Volcanic sublimates.	12	Oxidized zone of veins.
4	Inclusions in volcanic rocks.	13	Zone of secondary sulphide enrichment.
5	Pegmatites.	14	Saline residues.
6	Pyroclastic rocks.	15	Contact metamorphic zones.
7	Sedimentary rocks.	16	Regional metamorphic rocks.
8	Sands and gravels.	17	Minerals of recent formation.
9	Organic deposits.		

On the basis of this list, the minerals described in this report fall under No. 5, Pegmatites. A still more definite description would be that of "lithium-bearing granitic pegmatites." Such occurrences are not rare and have been found at many places in the world, as briefly described on pp. . The essential features of these occurrences are nearly all reproduced at each locality where lithium minerals similar to those from California are found.

The rock immediately surrounding the lithium-bearing pegmatites of California is a gabbro, very different in chemical composition from the pegmatites. Granite, however, is very abundant and if a genetic relation exists between the pegmatites and an exposed igneous rock, it is more likely to be the neighboring granite than the gabbro. Pegmatites are considered as emanating from a much larger magma, and the way in which the pegmatitic material is segregated from the main magma (see p.) strongly suggests that the area containing abundant pegmatite intrusions forms roofs overlying large bodies of granite masses, as suggested by Bastin.[30] If this be true, then the parent magma from which the pegmatitic material was derived need not be exposed on the surface and the correlation of the pegmatites with the present day exposed granites may be incorrect.

Association

The association of the minerals of the lithium-bearing pegmatites is characteristic and constant at the different localities. The minerals which constitute the pegmatite rock are few in number and very widespread in their distribution throughout the world. Quartz, orthoclase (including microcline), and albite, constitute at least 90 per cent of the California pegmatites. Small quantities of muscovite, garnet, and black tourmaline accompany the chief minerals.

The middle part of the pegmatites, with its cavities and minerals contained therein, yields a much larger number of species. Of these, several are very characteristic of lithium-bearing pegmatites and have been found at all the localities where extensive development has allowed detailed mineralogic collection and study. Minerals free from lithium assume a habit and variety which, though found at other occurrences, almost invariably occur with the lithium minerals. Quartz is abundant in well - developed crystals of the low temperature form; many of the crystals are clear

[30] Bastin, E.S., Geology of the pegmatites and associated rocks of Main: U.S. Geological Survey, Bull. 445, p.46, 1911.

and colorless, but crystals of smoky quartz are also abundant. Large crystals of potash feldspar, of a rectangular shape, due to large faces of c (001} and b (010), are abundant; many of them are perthitic. Albite, in tabular crystals flattened parallel to b (010]; muscovite, in wedge-shaped books; schorlite (black tourmalines) in thick prismatic crystals, especially if somewhat fibrous in structure and showing a gray tint- all these often indicate the presence of lithium minerals, although it must also be stated that at many places the above-named minerals occur abundantly in the forms stated and yet lithium minerals have not been found.

The two lithium minerals, lepidolite (generally pink or purple) and elbaite (lithium tourmaline, green or pink) are very characteristic of the occurrences of lithium. The other minerals in the accompanying lists are not so prominent and their quantity is so small that they may escape detection until the locality has been extensively developed by mining.

A compilation bas been made of the minerals reported from several of the best known and most exploited occurrences of lithium-bearing pegmatites with the results shown in the tabulations within. A marked difference in the relative abundance of some of the minerals is noted for the various lithium-bearing localities, for which difference the character of the lithium mica precut is a valuable discriminating criterion. If the lithium mica is lepidolite, the occurrence is in a well-defined pegmatite dike that fills an equally well-defined fissure. The country rock is very seldom enriched by material from the intruded lithium-bearing mass.[31] On the other hand if the lithium mica is zinnwaldite, then conditions are very different. The rock intruded is often cut by a network of small, ill-defined dikes or veins and is often attacked and altered to a greisen by the intruding lithium-bearing mass. In many such places no well defined pegmatite dike is present, but the intrusive was so rich in vapors or easily volatile substances as to readily penetrate, attack, and replace the intruded rock.

The list of minerals from lithium-bearing pegmatite dikes, exclusive of zinnwaldite-cassiterite occurrences. ---- meaning the mineral has not been reported from the area. Secondary minerals are italicized. [There are seven separate tables in this list].

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[31] The occurrence of the recently described holmquistite, a lithic glaucophane, seems to be an exception: Osann, A., Uber Holmquistit, einen Lithionglaukophan von der Insel Uto: Sitzber. Heidelberg Akad. Wissensch., math. naturw. KJ. Abth. A, p. 22 1913.

No.	Mineral	Composition	California	South Dakota	Maine	Massachusetts	Connecticut	Elba, Italy	France	Madagascar
										Localities
1.	Graphite	C	—	X[a]	—	—	—	—	—	—
2.	Bismuth	Bi	X	X	—	—	X	—	—	X
3.	Pyrite	FeS_2	X	X	X	—	X	—	—	X
4.	Galena	PbS	—	X[a]	—	—	—	—	—	—
5.	Molybdenite	MoS_2	—	X	X	—	—	—	—	—
6.	Bismuthinite	Bi_2S_3	X	X	—	—	—	—	—	X
7.	Tetradymite	Bi_2Te_2	—	X[a,b]	—	—	—	—	—	—
8.	Arsenopyrite	FeAsS	—	X	X	—	—	—	—	—
9.	Lollingite	$FeAs_2$	—	X	X	—	—	—	—	—
10.	Pyrrhotite	FeS	—	X[a]	X[c]	—	—	—	—	—
11.	Chalcocite	Cu_2S	—	X[c]	—	—	—	—	—	—
12.	Chalcopyrite	$Cu_2S \cdot Fe_2S_3$	—	X[a]	—	—	—	—	—	—
13.	Bornite	$3Cu_2S \cdot Fe_2S_3$	—	—	—	—	—	—	—	X
14.	Stannite	$Cu_2S \cdot FeS$	—	X	—	—	—	—	X	—
15.	Stibnite	Sb_2S_3	—	Xa	—	—	—	—	—	—
16.	Sylvanite	$(Au,Ag)Te_2$	—	X[a]	—	—	—	—	—	—
17.	Fluorite	CaF_2	X	X	X	—	—	—	—	X
18.	Yttrocerite	$(Ca,Y,Ce)F_{2-3}$	—	—	X	—	—	—	—	—
19.	Cuprite	Cu_2O	—	—	—	—	—	—	X	—
20.	Chalcedony	SiO_2	—	X	—	—	—	—	—	—
21.	Opal	$SiO_2 \cdot H_2O$	X	X	—	—	—	—	—	—
22.	Quartz	SiO_2	X	X	X	X	X	X	X	X
23.	Brookite	TiO_2	—	—	X[d]	X[d]	—	—	—	—
24.	Rutile	TiO_2	—	X	—	—	—	—	—	X
25.	Cassiterite	SnO_2	X	X	X	X	—	X	X	—
26.	Cuprocassiterite[e]	$CuOSnO_2H_2O$	—	X	—	—	—	—	—	—

[a] Not known definitely whether or not the occurrence is in a lithium-bearing pegmatite.
[b] Auriferous.
[c] Probably needs verification.
[d] Could columbite crystals have been mistaken for brookite?
[e] Composition not definitely known.

No.	Mineral	Composition	California	South Dakota	Maine	Massachusetts	Connecticut	Elba, Italy	France	Madagascar
										Localities
	Ilmenite	$FeO \cdot TiO_2$	—	X	—	—	—	—	—	X
	Strüverite[a]	TiO_2,FeO,Ta_2O_5	—	X	—	—	—	—	—	X
	Zircon	$ZrO_2 \cdot SiO_2$	—	X	X	—	—	—	—	X
	Spinel[b]	$R''O \cdot Al_2O_3$	X	X	X	—	—	—	—	—
	Gahnite[c]	$ZnO \cdot Al_2O_3$	—	—	—	—	—	—	—	X
	Magnetite	$FeO \cdot Fe_2O_3$	—	X	X	—	—	—	—	X
	Chrysoberyl	$BeO \cdot Al_2O_3$	—	—	X[d]	—	—	—	—	—
	Arsenolite	As_2O_3	—	X[d]	—	—	—	—	—	—
	Claudetite	As_2O_3	—	X[d]	—	—	—	—	—	—
	Limonite	Fe_2O_3,nH_2O	X	X	X	—(e)	—(e)	—(e)	—(e)	—(e)
	Hematite	Fe_2O_3	X	X	—(e)	—(e)	—(e)	—(e)	—(e)	X[f]
	Manganite	Mn_2O_3,H_2O	X	—(e)	—(e)	—(e)	—(e)	—(e)	—(e)	—(e)
	Psilomelane	MnO,MnO_2,H_2O	X	—(e)	—(e)	—(e)	—(e)	—(e)	X	—(e)
	Pyrolusite	MnO_2	—	X[g]	—(e)	—(e)	—(e)	—(e)	X	—(e)
	Bismite	$Bi_2O_3 \cdot 3H_2O$	X	X	—	—	X[d,h]	—	—	X
	Tellurite	TeO_2	—	X[d]	—	—	—	—	—	—
	Bismuthite	$Bi_2O_3 \cdot CO_2 \cdot H_2O$	X	—	—	—	X[d]	—	—	X
	Bismutosphaerite	Bi_2CO_5	X	—	—	—	X[d]	—	—	—
	Calcite[i]	$CaCO_3$	—	X[d]	X	—	—	—	—	—
	Siderite	$FeCO_3$	—	X[d]	—	—	—	—	—	—
	Rhodochrosite	$MnCO_3$	—	—	X	—	X	—	—	—
	Aragonite	$CaCO_3$	—	X[d]	—	—	—	—	—	—
	Bastnaesite	Ce,La,CO_2,F	—	—	—	—	—	—	—	X
	Malachite	$2CuO,CO_2 \cdot H_2O$	—	X	—	—	—	—	—	X
	Azurite	$3CuO,2CO_2 \cdot H_2O$	—	X	—	—	—	—	—	X
	Columbite[j]	$(Mn,Fe)O \cdot (Ta,Cb)_2O_5$	X	X	X	X	X	—	X	X
	Stibiotantalite[k]	$Sb_2O_3 \cdot Ta_2O_5$								
	Tapiolite	$FeO \cdot Ta_2O_5$	—	X	—	—	—	—	—	X[m]

[a] Placed with the oxides though more probably a tantalate. Essentially an isomorphous mixture of rutile and tapiolite.
[b] The composition of the spinels has not been determined. R'' probably represents Fe and Mn.
[c] Gahnite was also found in a lithium-free pegmatite in Maryland.
[d] Not definitely known whether the occurrence is in a lithium-bearing pegmatite.
[e] Doubtless present but not recorded in the literature.
[f] Specularite in splendent crystals.
[g] The distinction between pyrolusite and manganite may not always have been made.
[h] "Bismuth ocher."
[i] Abundant with spodumene (hiddenite) in North Carolina.
[j] Referring only to manganotantite, ferrotantalite, manganocolumbite, and ferrocolumbite.
[k] Including stibiocolumbite; also found in Australia.
[m] Tapiolite occurs in isomorphous mixture with rutile in strüverite.

No.	Mineral	Composition	Localities							
			Calif-ornia	South Dakota	Maine	Mass-achusetts	Connect-icut	Elba, Italy	France	Mada-gascar
	Microlite	2CaO·Ta₂O₅	X[a]	--	--	X	X	X	--	X[a]
	Hatchettolite	U,Cb,Ta[c]	X[c]	--	--	--	--	--	--	X
	Blomstrandite	Cb,Ta,Ti U[c]	--	--	--	--	--	--	--	X
	Betafite	Cb,Ti,U[c]	--	--	--	--	--	--	--	X
	Samiresite	Cb,Ta,Ti,U,Pb[c]	--	--	--	--	--	--	--	X
	Euxenite	Cb,Ti,U,Y,Er[c]	--	--	--	--	--	--	--	X
	Ampangabeite	Cb,Ta,Ti,U[c]	--	--	--	--	--	--	--	X
	Fergusonite	Y,Er,Cb[c]	--	--	--	--	--	--	--	X
	Samarskite	Cb,Ta,U,Y[c]	--	--	--	--	--	--	--	X
	Tschewkinite	Si,Ti,Ce,La,Di[c]	--	--	--	--	--	--	--	X
	Triplite	3(Mn,Fe)O·P₂O₅·MnF₂[b]	X	X	--	X	--	--	X	--
	Triploidite	4(Mn,Fe)O·P₂O₅·H₂O	--	--	--	--	X	--	--	--
	Amblygonite	Al₂O₃·P₂O₅·2LiF	--	X[d]	X[d]	X[d]	--	--	X	--
	Montebrasite	Al₂O₃·P₂O₅·Li₂O·H₂O	X	--	--	--	--	--	X	--
	Morinite	Al,Na,Ca,H,F,P[c]	--	--	--	--	--	--	X	--
	Soumannite	9CaO·2BeO·P₂O₅·CaF₂	--	--	--	--	--	--	X	--
	Apatite	Al,Na,P,F,H[c]	X	X	X	X	X	X	X	X
	Herderite	CaO·2BeO·P₂O₅·CaF₂	--	--	X[e]	--	--	--	--	--
	Lithiophilite	LiMnPO₄	X	--[f]	--	--	X	--	--	--
	Triphylite	LiFePO₄	--	X[g]	--	--	--	--	X	--
	Natrophilite	NaMnPO₄	--	--	--	--	X	--	X(?)	--
	Alluardite	MnO,Fe₂O₃,Na₂O,H₂O,P₂O₅[c]	--	--	--	--	--	--	X	--
	Childrenite	2FeO·Al₂O₃·P₂O₅·4H₂O	--	--	X	--	--	--	--	--
	Eosporite	2MnO·Al2O3·P₂O₅·4H₂O	--	--	--	--	X	--	--	--
	Cacoxenite	2Fe₂O₃·P₂O₅·12H₂O	--	X	--	--	--	--	--	--

[a] Not definitely determined as microlite.
[b] First described as hatchettolite.
[c] These are the essential elements.
[d] Including montebrasite. The distinction between amblygonite and montebrasite has not been made out.
[e] Not known definitely whether the occurrence is in a lithium-bearing pegmatite.
[f] Reported from South Dakota but probably triphylite.
[g] Griphite may be an altered triphyllite or triplite.

No.	Mineral	Composition	Localities							
			Calif-ornia	South Dakota	Maine	Mass-achusetts	Connect-icut	Elba, Italy	France	Mada-gascar
	Dufrenite	2Fe₂O₃·P₂O₅·3H₂O	--	X	--	--	--	--	X	--
	Palaite	5MnO·P₂O₅·4H₂O	X	--	--	--	--	--	--	--
	Hureaulite	5MnO·P₂O₅·5H₂O	X	--	--	--	X	--	X	--
	Salmonsite	Fe₂O₃·9MnO·P₂O₅·14H₂O	X	--	--	--	--	--	--	--
	Stewartite	MnFe₂(PO₄)₂·8H₂O	X	--	--	--	--	--	X	--
	Strengite	Fe₂O₃·P₂O₅·H₂O	X	X[a]	--	--	X[b]	--	X[b,c]	--
	Scorodite	Fe₂O₃·As₂O₅·4H₂O	--	X	--	--	--	--	--	--
	Barrandite	(Fe,Al)₂O₃·P₂O₅·H₂O	--	--	--	--	--	--	--	X
	Sicklerite	Fe₂O₃·6MnO·4P₂O₅·3(Li,H)₂O	X	--	--	--	--	--	X[e]	--
	Reddingite	3MnO·P₂O₅·3H₂O	--	--	--	--	X	--	--	--
	Dickinsonite	9(Mn,Fe,Na)O·3P₂O₅·H₂O	--	--	--	--	X	--	--	--
	Fillowite	9(Mn,Fe,Na)O·3P₂O₅·H₂O	--	--	--	--	X	--	--	--
	Fairfieldite	2CaO·MnO·P₂O₅·2H₂O	--	--	--	--	X	--	--	--
	Purpurite	Mn₂O₃·P₂O₅·H₂O	X	--[f]	--	--	X	--	--	--
	Heterosite	Fe₂O₃·P₂O₅·H₂O	--	X	--	--	--	--	X	--
	Monazite	(Ce,La,Di)₂O₃·P₂O₅	--	X	--	--	X	--	--	X
	Pyromorphite	9PbO·3P₂O₅·PbCl₂	--	--	--	--	--	--	--	X[g]

[a] Arsenical strengite.
[b] Vivianite is reported, but it is probably blue strengite.
[c] Called angelardite by Lacroix.
[d] Barrandite is an isomorphous mixture of strengite and vivianite.
[e] Possibly the same as Lacroix's pseudoheterosite.
[f] Reported from South Dakota but is heterosite.
[g] The presence of pyromorphite has led Lacroix to suggest the possible presence of original galena. Samiresite however contains lead.

No.	Mineral	Composition	Localities							
			California	South Dakota	Maine	Massachusetts	Connecticut	Elba, Italy	France	Madagascar
	Wavellite	$3Al_2O_3·2P_2O_5·12H_2O$	—	—	—	—	—	—	X	—
	Turquoise	$CuO·3Al_2O_3·2P_2O_5·9H_2O$	—	—	—	—	—	—	X	—
	Olivenite	$4CuO·As_2O_5·H_2O$	—	X [a, b]	—	—	—	—	—	—
	Libethenite	$4CuO·P_2O_5·H_2O$	—	—	—	—	—	—	X	—
	Pucherite	$BiVO_4$	X	—	—	—	—	—	—	X
	Autunite	$CaO·2UO_3·P_2O_5·8H_2O$	—	X	X	X	X	—	X	X
	Uraninite	$UO_2·UO_3$	—	X [a, b]	—	—	X	—	—	—
	Wolframite [c]	$(Fe,Mn)O·WO_3$	—	X [b]	—	—	—	—	X	—
	Molybdenite [d]	$Fe_2O_3·MoO_3·7 1/2 H_2O$	—	X [b]	—	—	—	—	—	—
	Scheelite	$CaWO_4$	—	X [b]	—	—	—	—	—	—
	Barite	$BaSO_4$	—	X [b]	—	—	—	—	—	—
	Copiapite	$2Fe_2O_3·5SO_3·18H_2O$	—	X [b]	—	—	—	—	—	—
	Melanterite	$FeO·SO_3·7H_2O$	—	X b	—	—	—	—	—	—
	Diadochite	$Fe_2O_3, P_2O_5, SO_3, H_2O$	—	X b	—	—	—	—	—	—

[a] Needs verification.
[b] Not definitely known whether occurrence is in a lithium-bearing pegmatite.
[c] Including hubnerite.
[d] Shaller stated "molybdenite" but gives the formula for ferrimolybdenite.

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No.	Mineral	Composition	Localities							
			California	South Dakota	Maine	Massachusetts	Connecticut	Elba, Italy	France	Madagascar
	Torbernite	$CuO·2UO_3·P_2O_5·8H_2O$	—	X	—	—	X	—	X	—
	Gummite	$(Pb,Ca,Ba)O_3·UO_3·SiO_2·6H_2O$	—	—	X	—	—	—	—	—
	Orthoclase	$K_2O·Al_2O_3·6SiO_2$	X	X	X	X	X	X	X	X
	Microcline	$K_2O·Al_2O_3·6SiO_2$	X	X	X	X	X	X	X	X
	Albite	$Na_2O·Al_2O_3·6SiO_2$	X	X	X	X	X	X	X	X
	Spodumene	$Al_2O_3·Li_2O·4SiO_2$	X [a]	X [b]	X	X [b]	X [b, c]	—	—	X [d]
	Eucryptite	$Al_2O_3·Li_2O·2SiO_2$	—	—	—	—	X	—	—	—
	Garnet [e]	$3(Fe,Mn,Ca)O·(Al,Fe^{+3})_2O_3·3SiO_2$	X [f]	X [g]	X [f]	—	X	X [h]	—	X [i]
	Topaz	$2AlF_2·Al_2O_3·3SiO_2$	X	—	X	—	X	—	X	X
	Andalusite [b]	$Al_2O_3·SiO_2$	—	X [j]	—	—	—	—	—	—
	Phenacite	$2BeO·SiO_2$	—	—	X [j]	—	—	—	—	—
	Titanite	$CaO·TiO_2·SiO_2$	—	X [j]	X [j]	—	—	—	—	—
	Muscovite	$3Al_2O_3·K_2O·2H_2O·6SiO_2$	X	X	X	X	X	X	X	X
	Lepidolite	$3Al_2O_3·3Li_2O·2K_2O·8F·12SiO_2$	X	X	X	X	X	X	X	X
	Zinnwaldite	Si,Al,Fe^{+2},K,Li,F [m]	—	—	—	—	—	—	—	X
	Biotite	Si,Al,Fe,Mg,K,H [m]	X	X	X	X	X	X	X	X
	Schorl (black tourmaline)	$12SiO_2·7Al_2O_3·5FeO·4H_2O$	X	X	X	X	X	X	X	X
	Elbaite (lithium-bearing tourmaline)	$12SiO_2·8Al_2O_3·2(Na,Li)_2O·4H_2O$	X	X	X	X	X	X	X	X
	Pollucite	$2Al_2O_3·2Cs_2O·H_2O·9SiO_2$	—	—	X	—	—	X	—	—
	Danburite	$CaO·B_2O_3·2SiO_2$	—	—	—	—	—	—	—	X
	Petalite	$Al_2O_3·Li_2O·8SiO_2$	—	X [k]	X	X	—	X	—	—

[a] The variety kunzite only.
[b] Only opaque white spodumene.
[c] Both the opaque white and kunzite varieties.
[d] Kunzite variety; pink, yellow, and pale green also.
[e] Used as a group name and including spessartite, alamandite, and grossularite.
[f] Spessartite and almandite.
[g] Spessartite, almandite, grossularite, and schorlomite.
[h] Spessartite.
[i] Spessartite, almandite, and glossularite.
[j] Not definitely known whether occurrence is in lithium-bearing pegmatite.
[k] Needs verification.
[m] Only essential elements listed.

No.	Mineral	Composition	Localities							
			California	South Dakota	Maine	Mass-achusetts	Connect-icut	Elba, Italy	France	Mada-gascar
	Beryl [a]	$2Al_2O_3 \cdot 6(Be,Cs_2,Li_2)O \cdot 12SiO_2 \cdot H_2O$	X	X	X	X	X	X	X	X
	Cookeite [b]	$3Al_2O_3 \cdot Li_2O \cdot 4SiO_2 \cdot 6H_2O$	X	--	X	--	--	--	--	--
	Allanite	Si,Al,Fe,Ce,La, Di,Ca,H [d]	--	--	X[c]	--	--	--	--	X
	Bityite	Si,Al,Ca,Be,Li,H [d]	--	--	--	--	--	--	--	X
	Manandonite	Si,Al,B,Li,H [d]	--	--	--	--	--	--	--	X
	Vesuvianite	Al_2O_3,CaO,SiO_2,H_2Oo	--	--	X[e]	--	X[e]	--	--	--
	Epidote	$3(Al,Fe)_2O_3 \cdot 4CaO \cdot 6SiO_2 \cdot H_2O$	X[c]	X[c]	--	--	--	--	--	--
	Serpentine	$3MgO \cdot 2SiO_2 \cdot 2H_2O$	--	X c	--	--	--	--	--	--
	Palygorskite	Al_2O_3,MgO,SiO_2,H_2O	--	--	--	--	--	--	--	X
	Talc	$3MgO \cdot 2SiO_2 \cdot 2H_2O$	--	X c	--	--	--	--	--	--
	Clays [f]	Al_2O_3,SiO_2,H_2O	X	X	X	X	X	X	X	X
	Stilbite	$Al_2O_3 \cdot (Ca,Na_2)O \cdot 6SiO_2 \cdot 6H_2O$	X	--	--	--	X	--	--	--
	Heulandite	$Al_2O_3 \cdot CaO \cdot 6SiO_2 \cdot 5H_2O$	X	--	--	--	X	--	--	--
	Laumontite	$Al_2O_3 \cdot CaO \cdot 4SiO_2 \cdot 4H_2O$	X	--	--	--	--	--	--	--
	Chabazite	$Al_2O_3 \cdot (Ca,Na_2)O \cdot SiO_2 \cdot 6H_2O$	--	--	--	--	X	--	--	--
	Prehnite	$Al_2O_3 \cdot 2CaO \cdot 3SiO_2 \cdot H_2O$	--	--	--	--	X	--	--	--
	Chlorite	$Al_2O_3 \cdot (Fe,Mg)O \cdot SiO_2 \cdot H_2O$	X	--	--	--	--	--	--	--
	Chrysocolla	$CuO \cdot SiO_2 \cdot 2H_2O$	X	--	--	--	--	--	--	--
	Hambergite	$4BeO \cdot B_2O_3 \cdot H_2O$	--	--	--	--	--	--	--	X
	Rhodizite	Al,Be,Li,K,Na,Cs,Rb,H,B [d]	--	--	--	--	--	--	--	X

[a] Includes common beryl and worobieffite (vorobievite--cesium-rich beryl)
[b] Probably present at nearly all the localities but not identified.
[c] Not definitely known if occurrence is in lithium-bearing pegmatite.
[d] Only essential elements are listed; oxygen is another chief constituent
[e] Could this be epidote?
[f] Kaolinite, halloysite, montmorillonite, and cimolite.

Each of these two types of lithium-bearing intrusives yields a characteristic set of minerals. Thus with zinnwaldite there is usually associated abundant cassiterite, whereas in the lepidolite deposits cassiterite occurs only in very minute quantities. Topaz is present in quantity with the zinnwaldite - cassiterite deposits, and is very rare in the lepidolite deposits. Red and green tourmalines are found in abundance with lepidolite and very rarely with zinnwaldite. Lead, zinc, silver, and bismuth sulphides occur in quantity with zinnwaldite but not with lepidolite. Tungsten minerals likewise are much more abundant in the zinnwaldite deposits. It is to be noted, however, that although there is a marked difference in the quantity of the minerals associated with lepidolite and zinnwaldite, respectively, yet the same minerals are found at both types of occurrence, and they represent the two ends of a continuous series of formation rather than two distinct types. The lepidolite occurrences show a much larger number of mineral species, due in part to the fore frequent presence of cavities in which later pneumatolytic action may change the composition of the minerals already formed.

The formation of zinnwaldite is at places considered as a secondary process. The original minerals of the rock are subjected to the action of vapors or solutions, containing F, B, Li, Sn, etc., which act through cracks and veins and change feldspar to tourmaline and biotite to zinnwaldite. See Langerfeld's[32] paper on the Cornish tin deposits.

Such a secondary lepidolite has not previously been described, but a single specimen from Pala seems to show an alteration of muscovite to lepidolite (described on p.).The associations given in the literature for the best known and exploited occurrences of pegmatite dikes containing the iron-free lithium-mica, lepidolite, are shown in the following tabulation. The individual mines or exposures have been grouped together into locality regions and the occurrences listed are as follows: California, South Dakota (the region near Hill City and Keystone, in the Black Hills); Maine (including Auburn, Minot, Poland, Hebron, Norway, Paris, Peru, and Rumford); and Massachusetts (Chesterfield, Goshen, Huntington); Connecticut (Branchville and Haddam Neck); Italy (Elba); France; Madagascar.

Sulphides are very rare in the lithium-pegmatites, yet seven distinct species

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[32] Langerfe!d, H., The structural and mineralogical features of the granitic rock of the tin ore deposits in Cornwall [In German]: Neues Jahrb. Min. Geol. Pal., Beil. Band, 28, pp. 1-49, 1909

have been reported. Bismuth is the only native element so far found. Haloids are exceedingly scarce, fluorite being the only one and that occurs in minute quantity at two of the localities tabulated. Oxides are rare with the exception of silica. Of the seven carbonates reported only two are regarded as primary. Tantalates and columbates occur in limited quantity by present manifold combinations, a total of 17 distinct species being given. Phosphates are abundant in number but limited in quantity, though their total is relatively greater than that of the sulphides, oxides (except quartz), haloids, carbonates, tantalates, and columbates put together. A total of 25 are reported, of these 14 are probably primary constituents of the pegmatites. One vanadate and three uranates (all secondary) are listed. Out of a total of 31 silicates (omitting the clays) a little more than half are primary minerals. Of the secondary silicates, the majority seem to be magmatic secondary ones (cookeite, bityite, the zeolites). Only one borate, hambergite, is known, though in the list are six borosilicates. Two-thirds of the silicates contain water (either as such, as hydroxyl, or as hydrogen). Counting the individual mineral species separately (schorlite, rubellite, manganocolumbite, ferrocolumbite, manganotantalite, ferrotantalite, spessartite, almandite, grossularite, etc.) a total of 110 mineral species are recorded as having been found in the lepidolite pegmatites. Including those of the other lithium micas (zinnwaldite, polylithionite, etc.) but excluding the uncertain occurrences in the Malay Peninsula and the lithium biotite from Italy, a total of 120 minerals is reached. Of these sixty are primary.

Scharizer further reports xenotime from the lepidolite pegmatite at Schuttenhofen, Austria. Unusual associations of lithium mica are the following: In the veins of Langesundfjord in Norway, zinnwaldite with aegirine and feldspar. Polylithionite from Greenland is associated with albite, analcite, steenstrupine, and aegirite. A lithium biotite from Italy has anhydrite and dolomite as associates. A lithium mica from the Malay Peninsula is reported is occurring in dolomite.

A few occurrences of lithium minerals have been described which seem to differ genetically from the more usual mode of occurrence. Among these are the lithium biotite of Beaume, Italy, described on page xx and found in gypsum and limestone, and the lithium-mica in limestone from the Malay Peninsula (see page xx). Detrital deposits of gem lithium minerals have yielded much material of value, especially in Ceylon and in Madagascar. These gem minerals have been derived from their virginal matrix by processes of erosion and concentration. Lithium also becomes concentrated in some secondary deposits of manganese (psilomelane, etc.), and has been found in pickeringite.

Order of succession

The minerals of the pegmatite have four well-marked epochs in their formation, and the minerals of each epoch have a characteristic chemical composition and also a characteristic form and size.

The first epoch is the formation of a compact granular and graphic rock-the upper and lower parts of the pegmatite dikes. Solidification is caused by cooling of the molten magma and the escape of mineralisers. The minerals formed, ·with the exception of quartz and spinel, are all silicates (spessarite, almandite, schorlite, biotite, muscovite, orthoclase, and microcline, albite). The rocks are fine to coarse grained, smaller in size than those of the second epoch but larger than those of the last two epochs.

The second epoch consists of the formation of the middle part with its coarse-grained rock, in which cavities are abundant. The first rock of the second epoch to form is a continuation of the upper part of the dike and is noted for the large size of

its constituent minerals, some of which are arranged normal to the general lay of the dikes. Although the rock solidified, in part, from a fusion, the magma was so rich in mineralisers (water vapor, etc.) that the formation of the rock represents a transition stage from a molten magma to a solution. The minerals formed are the same as comprise the first epoch, and in the latter stages of formation of the rock minute amounts of beryl, lepidolite, elbaite, etc., began to crystallize. The last part of the formation of second epoch is that portion of the middle part of the dike, which has been called the pay shoot. In it are found the cavities or pockets whose contents are so valuable for gem stones. The cavity linings and projecting crystals strongly suggest that the last stages of the second epoch were essentially crystallization from saturated solutions. The presence in these cavities of well-developed, large crystals, in which are concentrated elements absent from the other minerals (antimony in stibiotantalite) is best explained as growth from a solution.

With the exception of schorlite and biotite, the same minerals that formed the rock of the first epoch occur in the second epoch, but accompanying them are numerous other minerals not found in other parts of the pegmatite dike. In addition to the silicates-the most abundant-there are sulphides, oxides, fluorides, phosphates, tantalates, etc. The minerals found only in the second epoch of the California pegmatites are: lepidolite, elbaite, cacsic beryl, spodumene, montebrasite, apatite, bismuth, pyrite, cassiterite, columbite, fluorite, triplite, lithiophilite, topaz, and numerous secondary minerals. Although very minute crystals occur abundantly throughout the middle part of the dike, it is in this part that the minerals reach their maximum size

The third epoch marks the beginning of a new stage. The entire pegmatite dike has become solidified and, where there no cavities or cracks in the rock, further mineral formation would cease. But in the middle part of the dike cavities are abundant and in them waters, doubtless containing many elements in solution, are moving, attacking and dissolving some minerals and, as the temperature gradually cools, precipitating others. This epoch is the one of zeolitization and the minerals formed (cookeite, stilbite, heulandite, laumontite) are all hydrous silicates. It is probable that other minerals were also formed during this epoch, such as feldspar, clays, opal. The material from which the minerals of the third epoch were formed was entirely derived from preexisting minerals. Cookeite, a hydrous lithium silicate, was derived from elbaite lepidolite and spodumene, and the zeolites derived their substance from the feldspars. The minerals of the third epoch are much smaller in size than those of the two preceding epochs. No individual crystal of the third epoch was seen which exceeded a centimeter in length.

The fourth and last epoch is a weathering process and is in operation today. It consists characteristically in the introduction into the pegmatite of material from outside sources, namely meteoric waters, atmospheric constituents, and material derived from the neighboring rocks. Oxidation and hydration are the essential processes of change. The minerals formed are: Bismite, bismutite, bismutosphaerite, pucherite (the vanadium of which is probably derived from the gabbro adjoining the pegmatite dikes), hureaulite (in part), salmonsite, strengite, sicklerite, purpurite, oxides of iron and manganese, epidote (?) and opal {?). The individual crystal units of the fourth epoch minerals are very small, rarely exceeding a millimeter.

The order of succession of the pegmatite minerals in relation to the four epochs outlined as well as to each other is shown in the following tabulation. The order of pyrite, bismuthinite, and fluorite is unknown, as suitable specimens were not available.

PARAGENSIS OF PEGMATITE DIKES

Minerals	Composition	I Upper and lower parts	II Middle part Coarse aggregate Payshoots	III Zeolitization	IV Weathering
Spinel	$Al_2O_3 \cdot (Fe,Mn)O$				
Almandite	$Al_2O_3 \cdot 3FeO \cdot 3SiO_2$				
Biotite	$Al_2O_3 \cdot (Mg,Fe)O \cdot (K,H)_2O \cdot 3SiO_2$				
Schorlite	$7Al_2O_3 \cdot 5FeO \cdot 3B_2O_3 \cdot 12SiO_2 \cdot 4H_2O$				
Spessartite	$Al_2O_3 \cdot 3MnO \cdot 3SiO_2$				
Orthoclase					
Microcline	$Al_2O_3 \cdot K_2O \cdot 6SiO_2$				
Albite	$Al_2O_3 \cdot Na_2O \cdot 6SiO_2$				
Muscovite	$3Al_2O_3 \cdot K_2O \cdot 2H_2O \cdot 6SiO_2$				
Quartz	SiO_2				
Beryl	$Al_2O_3 \cdot (Be,Cs_2,Li_2)O \cdot SiO_2 \cdot H_2O$				
Columbite group	$(Fe,Mn)O \cdot (Cb,Ta)_2O_5; Sb_2O_3 \cdot (Cb,Ta)_2O_5$				
Spodumene	$Al_2O_3 \cdot Li_2O \cdot 4SiO_2$				
Montebrasite	$Al_2O_3 \cdot Li_2O \cdot P_2O_5 \cdot H_2O$				
Lithiophilite	$Li_2O \cdot MnO \cdot P_2O_5$				
Triplite	$MnF_2 \cdot 3MnO \cdot P_2O_5$				
Lepidolite	$3Al_2O_3 \cdot 3Li_2O \cdot 2K_2O \cdot 12SiO_2$				
Elbaite	$8Al_2O_3 \cdot (Li,Mn)_2O \cdot 3B_2O_3 \cdot 12SiO_2 \cdot 4H_2O$				
Apatite	$9CaO \cdot CaF_2 \cdot 3P_2O_5$				
Microlite					
Hatchettolite	$CaO,UO_3,(Ta,Cb)_2O_5$				
Cassiterite	SnO_2				
Topaz	$Al_2F_2O_2 \cdot SiO_2$				
Bismuth	Bi				
Palaite	$5MnO \cdot 2P_2O_5 \cdot 4H_2O$				
Stewartite	$3MnO \cdot P_2O_5 \cdot 4H_2O$				
Hureaulite	$5MnO \cdot 2P_2O_5 \cdot 5H_2O$				
Cookeite	$3Al_2O_3 \cdot Li_2O \cdot 4SiO_2 \cdot 6H_2O$				
Zeolites	$Al_2O_3,CaO,Na_2O,SiO_2,H_2O$				
Opal	SiO_2,H_2O				
Clays	Al_2O_3,SiO_2,H_2O				
Sicklerite	$Fe_2O_3, \cdot 6MnO \cdot 3(Li,H)_2O \cdot 4P_2O_5$				
Salmonsite	$Fe_2O_3 \cdot 9MnO \cdot 4P_2O_5 \cdot 14H_2O$				
Epidote	$3(Al,Fe)_2O_3 \cdot 4CaO \cdot 6SiO_2,H_2O$				
Chlorite	$Al_2O_3,(Fe,Mg)O,SiO_2,H_2O$				
Chrysocolla	$CuO \cdot SiO_2 \cdot 2H_2O$				
Bismite	$Bi_2O_3 \cdot 3H_2O$				
Pucherite	$Bi_2O_3 \cdot V_2O_5$				
Bismutite					
Bismuto-sphaerite	Bi_2O_3,CO_2,H_2O				
Strengite	$(Al,Mn)_2O_3 \cdot P_2O_5 \cdot 4H_2O$				
Purpurite	$(Mn,Fe)_2O_3 \cdot P_2O_5 \cdot H_2O$				
Manganese oxides	MnO,MnO_2,H_2O				
Iron oxides	Fe_2O_3,H_2O				

Successive generations of some of the pegmatite minerals

A few of the minerals show distinctly several generations, which can be differentiated as is done in the following tabulation. Other minerals do not allow of a distinction into separate generations but were formed both before and after another mineral. The period of formation of many of the minerals was a long one and of two minerals whose period of formation overlap, it is impossible to say definitely that one always preceded the other.

A criterion which may be of the greatest value in deciphering the various temperatures of solidification in the different parts of the pegmatite and fixing thereby, at least in part, the succession of formation of the minerals, is the determination of the inversion point of polymorphous minerals. In addition to a determination of the actual inversion point of the pure mineral, the effect of impurities and of associated substances must also be determined. Among the minerals to be thus studied, in addition to quartz, are orthoclase and microcline (?), albite and barbierite, ferrotantalite (columbite), and tapiolite.

Origin

The origin of the pegmatite minerals has been more or less suggested on the previous pages; hence a brief statement will here suffice.

The rock-forming minerals have crystallized from a molten magma which finally became so rich in mineralisers (among which is water vapor) that the process was one of crystallization from a solution rather than from a molten magma. The continuous process, extending from a molten magma to a water solution, obtained during the solidification of the entire pegmatite dike. Some changes took place in the molten magma, such as the change of schorlite to muscovite, lithiophilite to palaite, etc., but most of the changes were doubtless due to the effect of solution and water vapor, which were particularly active in the cavities of the middle part. The minerals found here, such as elbaite, stibiotantalite, apatite, were to a large degree the products of crystallization from a solution.

The results derived from the mineral studies, so far as they are related to the origin of the minerals, may be summarized as follows:

Crystallized from a molten magma: Spinel, almandite, spessartite, biotite, schorlite, orthoclase and microcline, albite, muscovite, quartz, beryl (alkali free).

Crystallized from a molten magma so rich in mineralizers as to approach a solution: Almandite, spessartite, schorlite, orthoclase and microcline, albite, muscovite, quartz, beryl, columbite group, spodumene, montebrasite, lithiophilite, triplite, apatite, microlite, hatchettolite, cassiterite, topaz, bismuth, elbaite, lepidolite.

Crystallized from a solution: All of the minerals listed above and in addition, palaite, stewartite, hureaulite, cookeite, zeolites.

The secondary minerals, sicklerite, pucherite, etc., also formed from solution though only by the addition or subtraction of material, the new product formed occupying the same space as the original mineral.

The detailed chemical reactions by which the alterations took place are discussed under the individual minerals.

Origins of pegmatitic dikes

Structural relations

The pegmatite dikes described fill fissures which are very regular in strike and in thickness, there being only a few exceptions to this regularity. The dikes have been observed through a stretch of country for nearly 50 miles and the vast majority of them have a northwest to southeast strike, in which direction many of them extend for hundreds of feet, some for thousands of feet. This marked uniformity of strike at once suggests the possibility of correlating the fissures now filled with the pegmatite rock, with the main physiographic and tectonic directions of California which similarly have a northwest-southeast direction. The main mountain ranges-the Sierra Nevada, the Coast Range, the Cascades, the Peninsula Range extending into Lower California; the two main rivers of the state, the Sacramento and the San Joaquin, paralleling the axis of the great valley of California; the shore line of the Pacific Ocean; the earthquake fault line passing through San Francisco; have the same general northwest-southeast direction as partly shown in figure 1on p.

Considering the fissures by themselves and disregarding for the moment the character of their filling, it seems most reasonable to expect a satisfactory correlation of the formation of the fissures with the other named features of the state. The western part of southern California is known to have undergone frequent oscillations especially

west of the gem tourmaline field wherein lie the pegmatite dikes.

The structural relations of the pegmatite ledges to the country rock, which in nearly all cases is of gabbroic character, are such as to show that the pegmatite was intruded into the gabbro. The fact that the gabbro where not altered is a granular compact remarkably hard rock shows that regular fissures must have formed in it which allowed the entrance of the pegmatitic material.

These fissures have no genetic relation to the gabbro. This is shown by the fact that the direction of the fissures is the same in different gabbro bodies many miles apart and separated by various kinds of rocks. The gabbro is everywhere traversed by small fissures, seldom over several centimeters wide, which are filled ·with similar gabbroic material. These fissures run in every direction and no doubt are directly related to the gabbro being very likely filled shrinkage cracks. These small gabbro-filled fissures are cut by the pegmatite dikes (See plate) which are therefore later, and formed long after even the shrinkage cracks in the gabbro had solidified.

The conclusion reached is then that the fissures were produced in the gabbro long after it had consolidated. The pegmatite material taken by itself can hardly be considered as the fissuring agent; much more probable would be the intrusion of a granitic magma into the gabbro, forming in it a series of parallel fissures which were filled by the pegmatitic material. This pegmatitic material is however generally considered in the nature of a residual mass of a huge magma. Now, if the intrusive action of the granite fissured the gabbro, there would be no residual pegmatitic material ready to fill these fissures. Moreover the granitic magma itself would fill any fissures which certainly would not remain open until the pegmatitic residual material had formed.

It seems more probable therefore that the fissuring was caused by a tectonic movement which formed fissures in the compact rigid gabbro rock and that these fissures reached an accumulation or "residual mass" which formed the present pegmatite rock. The large magma from which the pegmatitic material was derived had no relation to the fissuring of the gabbro. The gabbro has been subjected to at least three disturbances: (1) contraction, due to cooling, the contraction cracks filled with gabbro rock; (2) fissuring by tectonic forces, the fissures now filled with pegmatite; (3) faulting and jointing (Plate IIA.), joining lines of access of atmospheric agencies which cause the disintegration and weathering of the gabbro.

Source of material

The material forming pegmatites is considered as derived from a magma by processes of differentiation. The magma contained, in addition to its normal chemical constituents, certain ones which by their catalytic action, mobility and other properties considerably change the character of a solidifying rock. These certain elements are called mineralizers and a part of them at least are in a gaseous state dissolved in the magma. In the original magma, these mineralizers are widely distributed but after the magma has reached the position where it gradually cools and solidifies, these mineralizers may become concentrated in one position of the magma, generally at its upper portion, for these mineralizers are not as heavy as the molten rock. That portion in which these mineralizers are concentrated forms the pegmatitic material which is defined by Lindgren[33] as a "magmatic extract" which in a state of aqueo-igneous fusion, "is a hot mixture of fluid material and dissolved gases." It can readily be seen that the quantity of these "dissolved gases" will have a very marked influence on the

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[33] Lindgren, W., Mineral deposits, p. 1913.

character of the final rock. Considering magmatic extract in general, the amount of these "dissolved gases" or mineralizers, may be described as very abundant, not very abundant, and absent or nearly so.

A magmatic extract in which the mineralizers are very abundant will, in cooling, try to discharge them. If the conditions are such that the mineralizers cannot escape, they will accumulate in the upper portion of the magma and will energetically attack the surrounding rock and metamorphose it to a large extent. The mineralizers themselves will enter largely into the composition of the final solidification. The occurrence of cryolite at Ivigtut in Greenland, is probably an example of such an occurrence for, as described by Baldauf 34, an immense deposit of cryolite, a sodium aluminum fluoride, forms the upper portion of a pegmatitic intrusion. The cryolite contains sulphides and carbonates and the surrounding rock is intensely metamorphosed.

The cooling magma, however, is able to discharge the mineralizers into the surrounding rock, then the type of deposit known as "cassiterite veins" forms. The intruded rock is converted into greisen and a characteristic set of minerals is deposited in quantity. These minerals are: cassiterite, molybdenite, arsenopyrite, wolframite, bismuthinite, bismuth, pyrite, chalcopyrite, galena, sphalerite, fluorite, apatite, topaz, zinnwaldite, beryl, and many others. The characteristic features of this type are the abundance of cassiterite and of topaz and the spreading out of these minerals into the surrounding rock.

The second type of magmatic extract is that in which the mineralizers are not very abundant. If they are unable to escape from the original magma and become concentrated into one large body at the upper portion of the magma, then they will be caught in the solidifying magma, and will form small pegmatitic druses scattered throughout a large rock mass. The druses in the granite of Striegan, Silesia, are apparently of this origin.

If, on the other hand, the not very abundant mineralizers can concentrate at the upper surface of the magma, they will form with the solidifying rock, a mass of pegmatite, with gradual gradation into the normal igneous rock. If this concentrated magmatic extract can escape, before solidification, into the surrounding rock by means of fissures, it will form pegmatite dikes in which on cooling a still further concentration of the mineralizers takes place. The California pegmatites, described in this report, are typical of such occurrences.

The last type of magmatic extract in which the mineralizers are nearly absent will form the ordinary quartz-feldspar pegmatites which contain no rare minerals or cavities and in which the action of these mineralizers is typically absent.

Chemical composition

The chemical composition of the pegmatite dikes has been given by a small series of analyses. These analyses show that the composition of the different pegmatite dikes is rather uniform. Such slight variation as is shown is not necessarily inherent in the pegmatites but may be caused by the sample analyzed not being sufficiently representative. The rocks are so coarse grained that a very large sample should be thoroughly mixed and quartered down. This could not be done as well as would be desirable as the greater part of the material collected in previous years was lost in a fire. The results obtained however are sufficiently representative to ser the purpose. It is an interesting fact that the chemical and mineralogical composition of the

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[34] Baldauf, A. Cryolite in Greenland: Zeitsch, prak. Geol., vol., p. 1910.

unsymmetrical type of pegmatite is essentially the same as that of the granular homogeneous type. Though the cases in which this can be actually demonstrated are few in number yet nothing was observed at any of the occurrences to indicate that more extended analytical work would yield different results. The essential identity in composition of these pegmatites as well as the similarity in composition of all the California pegmatites analyzed is shown in the following tabulation. In the pegmatite from the Katerina mine, Pala, the result shown is the average of the two analyses of the lower banded rock and the upper graphic granite. It is to be noted that the middle part is omitted from all the California pegmatites analyzed. Its inclusion would not materially change its composition, as shown on page

Comparison of composition of California pegmatites.

OXIDES	Caterina mine, Pala, Average of upper & lower parts.	Rincon. Granular quartz-feld-spar rock.	Anita mine Riverside Co. Graphic quartz-feldspar rock.
SiO_2	73.55	74.74	73.93
Al_2O_3	15.00	15.38	13.77
Na_2O	4.01	4.20	2.00
K_2O	5.15	4.26	9.16
H_2O	0.51	0.58	0.16
Fe_2O_3	0.52	0.77[a]	0.25
FeO	0.50		0.19
MnO	0.45	0.04	0.03
CaO	0.21	0.26	0.48
MgO	0.00	0.03	0.08
Li_2O	trace	0.00	trace
	99.90	100.26	100.05

[a] Expressed as FeO.

MINERALOGY

	Caterina mine	Rincon	Anita mine
Albite	34	36	17
Anorthite	1	1	2
Quartz	30	31	25
Microcline[b]	25	19	54
Muscovite	8	9	–
Garnet	2	1	–
Tourmaline	–	3	2
	100	100	100

[b] Including orthoclase.

It is difficult to express accurately the chemical composition of the pegmatite dikes as a whole with special reference to the rarer elements of the pay shoot. The greatest observed development of the pay shoot was less than half of the entire dike and very rarely does it amount to ten per cent. Even the middle part, of which the pay shoot is only a portion does not average ten per cent of the entire dike. Then too, of the hundred dikes observed at Pala, less than ten had a pay shoot. The distribution of the pay shoot is so irregular that its relative percentage can hardly be even estimated.

The large dike on Stewart Hill at Pala contains practically no pay shoot at its northern end, whereas at its southern end, at the Stewart Mine, it forms possibly a third of the dike at its thickest point.

After due consideration of the observed facts, the following values have been taken as most accurately representing the relations, realizing however, that at the best they are but crude approximations. The error is certainly in the direction of giving too large values rather than too small ones. Ten per cent of the ledges contain pay shoots. The pay shoots are so irregularly distributed that they form but one per cent of the entire dike. The mineral composition of the pay shoot is estimated as:

Estimated mineral composition of pay shoot.

	Per cent.			
Quartz	42	SiO_2	=	74.7
Albite	25	Al_2O_3	=	14.8
Microcline	12	Na_2O	=	3.6
Lepidolite	8	K_2O	=	3.5
Tourmaline	6	Li_2O	=	.9
Muscovite	3	F	=	.8
Spodumeme	2	B_2O_3	=	.7
Garnet, beryl	1	H_2O	=	.6
Phosphates,		MnO,FeO	=	.2
Tantalates, etc.	1	P_2O_5	=	.1
	100	etc.	=	.1
				100.0

Excepting for the greater quantity of rarer elements, the composition of the pay shoot is very similar to that of the pegmatites. Considering now that the above given composition forms one per cent of the total pegmatite matter, the average composition of the California pegmatites becomes as follows:

Estimated average composition of California pegmatites as a whole.

SiO_2	=	73.89
Al_2O_3	=	15.07
Na_2O	=	4.02
K_2O	=	5.12
Li_2O	=	.01
F	=	.01
B_2O_3	=	.21
H_2O	=	.45
(Mn,Fe)O	=	1.21
P_2O_5	=	.001
Etc.	=	.001
		99.99

Two very interesting comparisons can be made with the above given analysis, namely with the average composition of igneous rocks in general, and with the average composition of granite, the parent rock from which pegmatites are universally considered as being derived. Comparison of average composition of California pegmatite with the average composition of igneous rocks and the average composition of granites.

	Average composition of igneous rocks.[a]	Average composition of California pegmatites.	Average composition of granites[b]
SiO_2	59.93	73.89	69.92
Al_2O_3	14.97	15.07	14.78
Fe_2O_3	2.58	0.00	1.62
FeO	3.42	.60	1.67
MnO	.10	.61	0.13
MgO	3.85	0.00	0.97
CaO	4.78	0.00	2.15[f]
Na_2O	3.40	4.02	3.28
K_2O	2.99	5.12	4.07
H_2O^{--}	.47	0.00	
H_2O+	1.47	0.45	0.78
TiO_2	.74	0.00	– –
Li_2O	.01[c]	0.01	– –
F	.10	0.01	– –
B_2O_3	less than .01	0.21	– –
P_2O_5	.26	0.001	.24
X	.99[d]	0.001e	– –
	100.00	100.00	100.00

a) Clarke, F.W., The data of geochemistry: second edition; Bull. 491, U.S. Geol. Survey, p 27, 1911.

b) Daly, RA., Igneous rocks and their origin, p. 19 (no. 4), 1914.

c) Probably too high as a "trace" in an analysis is reckoned as 0.01per cent.

d) Including: ZrO2,. 0.03; CO2,. 0.48; S, 0.11; Cl, 0.06; BaO, 0.11; SrO, 0.04; NiO, 0.03; Cr2O3, Including: Cb, Ta, Bi, Sb.

e) Including .06 per cent BaO and .02 per cent SrO.

Comparing the first two analyses, it is to be noted that the silica percentage is considerably above the average value, as is to be expected for a granitic pegmatite is a persilicic rock. The total or nearly total absence of FO3, MgO, CaO, TiO2 is striking. The amount of FeO is much below the average, on the other hand the percentage of MoO is six times as great. The alkalies Na2O and K2O are both present in greater amount though only about half as much again. Comparing now the last two analyses, the average composition of the California pegmatites shows a little more silica than the

average composition of granites but there is a marked decrease in the iron, magnesia, and lime. The alkalies are both higher, the increase being about 25 per cent. The small amount of lithium in the pegmatite analysis is surprising. The only elements in which a decided concentration has taken place are Mn and B.

Formation of pegmatites

Homogeneous type.

The homogeneous type of pegmatite represents a coarse-grained granular rock which, although of wide-spread abundance, presents so little of strictly mineralogical interest that the occurrences were very little studied. The long distance which some of the narrow dikes reach, as the small stringer at Mesa Grande, (page) indicates that the injected material must have possessed considerable fluidity. No indications were seen that would suggest an origin other than that of the injection of a molten magma.

Symmetrical type.

The characteristic feature of the symmetrical type of pegmatites is the similarity of the upper and lower parts of the dike which is divided by the central band or middle part which is very coarse in texture and in which are concentrated the rarer elements, such as fluorine, lithium, phosphorus, etc. The middle part is not a continuous formation throughout the entire dike but swells and pinches and disappears at places where the upper and lower parts then come together.

The fissure filled ·with intruded pegmatitic material was surrounded by a cooler rock and the extreme upper and lower portions of the pegmatitic material therefore cooled faster and solidified first. The solidification of this thin layer prevented the escape of any of the constituents of the pegmatitic magma into the surrounding gabbro and confined the action of all these constituents to the pegmatite itself. The magma which eventually formed the symmetrical group of pegmatites had a temperature so low that solidification commenced very soon after its intrusion. Both the upper and lower parts began to freeze before the gaseous material had much chance to become concentrated in any one portion. The freezing magma thus forced the gaseous material up from the bottom and down from the top (figure 15 a, b, c, and d) concentrating it in the central portion where it formed the "middle part".

Figure 15 Sketch of successive stages in the solidification of a magma eventually forming a pegmatite of the symmetrical type; a, the magma at the time of intrusion; b, c, d, successive stages during the solidification; e, the final stage resulting in the formation of the middle part. Light areas represent liquid magma. Dark areas represent solidified rock. The small circles signify the mineralizers or gaseous materials and the attached arrows the directions in which these moved during the successive stages of solidification.

The minerals of the middle part with its pay shoot form many interesting modes of occurrence, succession, alteration, etc., which have been described in some cases in considerable detail. The list of minerals is given at the beginning of Part m and need not be repeated here.

The minerals of the middle part, as well as those of the upper and lower parts, have their polyvalent elements in the lower state of oxidation-the iron is chiefly ferrous, the manganese chiefly manganous, bismuth occurs native, etc., suggesting that the

material of the pegmatitic magma has either been subjected to atmospheric exposure for the first time or **if** it is a former rock remelted, it has been subjected to very strong reducing agents.

The mineralizers being confined to the inner part of the pegmatite by the protecting walls of frozen pegmatite layers, were very concentrated by the time the upper and lower parts of the pegmatite were formed and by this very concentration lowered the freezing temperature and reduced the "Viscosity of the remaining magma still more. **It** has even been suggested that Li, F, B, etc. act as cyclical catalyzing agents but experimental evidence is badly needed for solving these questions. The action of these mineralizers was extremely energetic in their narrow confinement and the results produced are shown in the wonderful crystals produced (Plate formations.) and the various constructive and destructive From the fact that these mineralizers postpone the solidification point, it may be inferred that they would be concentrated in the minerals last to form and that therefore an examination of these last formed minerals would give a clue as to what the mineralizers are.

Attention may be called to the fact that most of the primary minerals of the pay shoot are not simple compounds, but are members of an isomorphous series, that is, they are solid solutions. Compare columbite (Fe,Mn)O (Cb,Ta)$_2$O$_5$; stibiotantalite (Sb$_2$O$_3$) (Ta,Cb)$_2$O$_5$; montebrasite Al(Li,Na) (F,OH) PO$_4$; triplite (Fe,Mn) F PO$_4$; lithiophilite (Mn,Fe) Li PO$_4$; the feldspars, tourmaline, garnet, beryl, lepidolite, topaz; etc.

Out of 13 minerals listed under I, three contain water, four fluorine, one boron, four lithium, three manganese, two soda (only in small amount-beryl and tourmaline) and none potash.

Among the seven minerals listed under II, two contain water, one fluorine, one boron, one lithium, one manganese, two soda and one potash. Under III, are given five minerals, of these, three contain water, one fluorine, one boron, one lithium, one manganese, three soda and two potash. Out of 10 minerals under IV, seven contain water, one fluorine, no boron, one lithium, two manganese and four soda and one potash. Under V are listed 15 minerals. Thirteen of these contain water, none fluorine, boron or lithium, seven manganese and none soda or potash. Expressing these facts in terms of percentages, the following tabulation is obtained.

Percentage of minerals, containing certain
elements of different periods.

Period	1	2	3	4	5
Element					
H_2O	23	30	60	70	87
F	31	0	20	10	0
B	8	14	20	0	0
Li	31	0	20	10	0
Mn	23	0	20	20	46
Na	15	30	60	40	0
K	0	14	40	10	0

The general tendency for the magma is to increase in water, boron, soda and potash and to decrease in fluorine, lithium, remaining nearly constant for manganese.

Unsymmetrical type.

The unsymmetrical type of pegmatites on the other hand have a different structure. They consist of three distinct parts, called respectively the upper, middle and lower parts. The lower part is believed to have been the first to form and the middle part the last to form.

The lower part of these pegmatites is a medium grained rock which in comparison to the texture of the upper and middle parts is very fine-grained. A very marked feature of many of these lower parts is that the garnets are arranged in numerous wavy parallel bands at places throughout the entire extent of the lower part. At other places they extend only through a portion of the lower part. At still other places these bands are entirely absent.

The relations of the three parts to one another are very important. The middle part bears the same relation to the upper part as holds for the first-group pegmatites, namely, a perfect gradation between the two so gradual that a limiting line cannot be accurately placed. On the other hand the contact between the middle and the lower parts is very sharp and well defined, the upper surface of the lower part being at many places a fairly plane surface. Though at some localities the two parts are firmly welded together at others the middle part is easily removed baring the smooth upper surface of the lower part. This is especially the case where the middle part is very coarse grained and cavernous as that by weathering processes it becomes friable and easily broken.

Another very important fact is that in all observed cases where the pegmatite was not displaced (and only one such possible locality was seen) the relative positions of the three parts was always the same. The finer-grained banded rock was always on the bottom; the graphic granite part was always on top and the cavernous pay shoot with its lithium minerals was always in the middle.

The pegmatites of the unsymmetrical type showing distinctly the lower finer-grained par t, the upper graphic granite part and the intermediate middle part, require a somewhat different explanation of the successive stages of formation from that given for the symmetrical type. The magma which eventually formed these unsymmetrical pegmatites had a temperature, after its intrusion, considerably above its freezing point and therefore remained liquid (except for a thin shell of solid roc k on the extreme upper and lower sides) for a long time permitting the removal of the gaseous material from the lower half and its concentration in the upper half. Through the action of gravity, the gaseous materials rose, impoverishing the extreme lower portion of the magma and gradually enriching the upper part. Thus, although the extreme upper and lower sides of the magma had an equal temperature (lowered by the adjacent cooler gabbro), the lower part froze first while the upper part remained liquid due to the gradually increasing concentration of the gaseous material which lowered the freezing point.

The conditions so far outlined are shown diagrammatically in figure 16 which represents the successive stages in the gradual solidification of the pegmatite magma. In Figure 16a is depicted the magma immediately after intrusion. It is all liquid and the gaseous material is beginning to ascend and in 16c the extreme bottom layer has become so impoverished that it is solidifying while the extreme upper layer has become so enriched with the gaseous material that it remains liquid although its temperature has fallen to the same value as the extreme bottom layer.

The bottom part continues to solidify, the top portion meanwhile become richer in the gaseous materials (d and e). At a certain time however the extreme upper part has reached a temperature at which even the abundance of the gaseous material does not suffice to keep it liquid and it solidifies at the upper edge as here the temperature is the lowest (d). Just how far the lower half of the magma had solidified when the top layer began to freeze is of course not known. The relative conditions illustrated are purely arbitrary.

Figure 16 Sketch of successive stages in the solidification of a magma eventually forming a pegmatite of the second group. a, the magma at the time of intrusion; b, c, d, e, f, successive stages during the solidification; g, the lower part has ceased to grow; h, the final stage resulting in the formation of the middle part. light areas represent liquid magma. Dark areas represent solidified magma. The small circles signify the gaseous material and the attached arrows the direction in which the gaseous materials move during the successive stages.

The freezing of the upper part extends downward (d, e, f) and as the gaseous materials cannot combine chemically with the minerals being formed (quartz, feldspars) they are "squeezed out" and all pushed downward, retracing their former steps. Finally the conditions shown is g are reached. The gaseous materials, now traveling downward, have reached the solid surface of the lower part of the magma and can travel no further. The lower part of the magma forming the finer-grained banded rock is now completely solidified. The upper coarser graphic granite is also completely formed. In between lies the remaining magma highly concentrated in gaseous material and still liquid,

If the gaseous material consists chiefly of hydrogen or in its combined form, water, there will be no middle part. The water formed, however, will act on the lower surface of the upper part partially dissolving it and pitting its surface by corrosion. These corrosion holes have been observed at two places on Hiriart Hill (page). If, on the other hand, the gaseous materials are rich in Li, Be, P, B, F, Bi, Ta, Cb, Sn, and Sb,

they will have become so concentrated that the magma can no longer hold them and they will unite with the silica, alumina, soda, potash of the magma and form the minerals of the middle part (h, figure   ).

The hypothesis outlined above necessitates the movement of Li, Be, P, Bi, Ta, Cb, Sn and Sb with the gaseous materials. In what form these bases are combined so that such heavy elements like B, Ta, Cb, Sn and Sb can ascend through a magma is not known. The concentration of these heavy elements in a certain small portion of the pegmatite magma is a problem at present unexplained. It is impossible to think that they retained this central place in the pegmatite during its intrusion and even if this were so, their original concentration in a certain portion of the original magma from which the pegmatite magma was derived would require a similar explanation. The assumption is therefore justified that these heavy elements were distributed through the pegmatite magma after its intrusion but before its solidification, and moved with the gaseous material.

The coarseness of the rock formed is directly related to the abundance of these gaseous elements. The lower part is finer-grained because most of the gaseous material had been removed before the rock solidified. The upper graphic granite part which formed in the presence of considerable amounts of the gaseous material is very coarse-grained and the coarsest of all the three parts is the middle part in which the gaseous materials were most highly concentrated.

The lower part is supposed to have formed after the removal of the gaseous materials; the graphic granite on the other hand was formed in the presence of an abundance of these gaseous materials. Is the graphic structure due to the presence of a considerable amount of these same gaseous materials or are the canal-like lines of the graphic granite, now occupied by quartz or albite, the passages through which these gaseous elements were "squeezed out?"

The idea of graphic granite being a eutectic deserves only a few lines. The explanation offered in the preceding paragraphs, if valid, shows that the graphic granite could not have been solidified last. Every fact observed points to the middle part having been formed after the graphic granite. The large tourmaline crystals growing from a black "root" in the graphic granite through blue and green to the red end of the middle part; the presence of small offshoots carrying lithium minerals from the middle part penetrating the graphic granite, etc., show conclusively that the graphic granite did not form last.

A eutectic must necessarily be the last solidification. Graphic granite is therefore not a eutectic. Bastin[35] comes to a similar conclusion for after calling attention to the fact that graphic granite consists of three minerals-quartz, microcline (including orthoclase) and a plagioclase feldspar, he states:

"It should be pointed out, moreover, that if water or other gases were present, as it is almost certain they were, they formed additional components whose amount the analyses do not reveal, but whose influence on the proportions of the other constituents may have been great. If graphic granites crystallized from magmas of eutectic proportions these were therefore eutectics of at least four components. The series of analyses, though suggesting that the proportions between the constituents of graphic granites are controlled by some laws, can hardly be regarded as proving their eutectic origin....[In some cases] the graphic granite was unquestionably not the last crystallization from the magma.... there can be no reasonable doubt that these gem and cavity bearing portions rather than the bordering graphic portions were the

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[35] loc-cit., p. 42

last parts of the pegmatite to crystallize."

It is believed that the process of formation of the banded structure (compare Plate) was somewhat as follows. After intrusion of the pegmatitic material, a thin layer of frozen rock formed on the extreme bottom. This layer is free from any banding of garnets. Meanwhile the temperature of the magma was gradually becoming less and less and the dissolved gaseous materials were concentrating in the upper part of the magma. The extreme lower part was thereby becoming more viscous because of the lowering of temperature and the loss of the viscosity-retarding substance (the gaseous material). On the other hand, the upper part was not becoming viscous at the same speed as although the temperature was declining at a similar rate, the increasing amount of the gaseous material helped to ward off the increasing viscosity. The stage was reached where garnets were separated out of the magma, that is, the saturation point of the garnet was reached. These garnets, by virtue of their relatively high density, sank in the magma and accumulated at the bottom. Some of the garnets never passed through a magma which was not over-saturated with them. Consequently these garnets continuously grew and formed the perfect idiomorphic crystals now observed. Other garnets, before they came to rest, passed through a magma which partly resorbed them and these corroded garnets are found mixed heterogeneously with the well formed ones.

Some of these garnets sank in the magma becoming thereby often huddled together into small groups, as shown in figure on page x. They continued to sink until they reached a stratum in which the viscosity was so great (due to freezing) that they could sink no further. Here they remained, the rock solidified, and a band of garnets was formed. The material displaced by the heavier garnets consisted of the less viscous substances, alumina and soda which thus become concentrated immediately above the garnets. It froze before many garnets had become embedded therein, and thus formed a layer of nearly pure albite. Above this was again concentrated a layer of garnets which became embedded in the freezing magma. The process was repeated many times and the successive bands of garnets formed. The thickness of a band depended on the viscosity of the magma surrounding the garnets. If this was low, a thick band accumulated before it solidified whereas if the viscosity was high, only a thin band could form.

The wavy character of the bands may be due to the fact that the radiation of heat did not go on uniformly so that points of equal temperature would not lie on a straight line parallel to the wall of the pegmatite ledge but on a wavy one similar in character to the wavy bands of garnets, as shown in Plate

The preceding paragraph presuppose that all of the pegmatitic material was intruded at one time and that the resultant differentiation took place in the fissures which are now filled by the pegmatites. If a second intrusion took place, as suggested for example by Waring36 then why should this second intrusion always have taken place on the same side of the filled fissure? If two (or more) intrusions were necessary to form the single dikes as they can be seen today, then the first intrusion must have been the finer-grained, usually banded rock. For if the graphic granite (upper part) had formed first, then the cavities existing on its lower side (in what is called the middle part) must have been filled by the material of the second intrusion. But the finer-grained banded rock nowhere extends into the cavities. And surely no one would suggest that three separate intrusions took place (forming the three parts) and that both the second

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[36] Waring, GA., The pegmatite veins of Pala, San Diego County: American Geologist, vol. 35, p. 336, 1905

and third intrusions always occurred on the same side of the previous intrusion. The middle part, moreover, is not a continuous formation but consists of irregularly shaped masses not connected and are, in their relation to the upper graphic granite, similar to those of the first group pegmatites for which no second intrusion is called for. Moreover why should then there not be occurrences of this first intrusion by itself? No pegmatite dikes have been seen anywhere in the field which correspond throughout in structure to the lower banded part.

The structure of these pegmatites must then be explained as the results of processes operative after the entire pegmatite mass had been intruded in the single intrusion. This single intrusion may well have been a slow and long drawn out one and may have consisted of several epochs during which material was added to the pegmatite magma. But all material was added to the pegmatite magma before any solidification took place and I am more inclined to believe that a single intrusion furnished all the material.

The gabbro rock into which the pegmatite was intruded is altered for a considerable distance below the present surface. The character of the alteration and the presence of hard residual nuclei of gabbro adjoining the pegmatite shows that the alteration is due to ordinary weathering processes and cannot in any way be traced to the effects produced by the presence of the pegmatite as described in detail in pages xyz. Moreover, no mineral was observed in the gabbro which can claim in the pegmatite as a source of even a part of its material. In other words, the pegmatite intrusions had no effect on the gabbro which produced results now detectable. Similar conditions are stated by Bastin[37] for the Maine pegmatites.

"Field observations in Maine fail to show that contact-metamorphic effects due to the intrusions of pegmatite are notably greater than those produced by the granites. The effects produced by both are usually slight and in many instances almost nil."

If by a vein is meant material which owes its fluidity to water and by dike material which owes its fluidity to high temperature, then the California pegmatites are certainly dikes and not veins. A very small portion of the entire pegmatite (parts of the pay shoot) may be veins, but the pegmatites as a whole are not. The term aqueo-igneous has been applied to pegmatites but the term itself is merely a compromise between the terms veins and dikes for it means a dike containing considerable water. But where can the line be drawn between a true dike and an aqueo-igneous dike and what constitutes a true dike? All dikes contain water in at least one of their constituent minerals and the amount of gaseous material, largely water, which was originally present in the dike is not known.

The California pegmatites are similar in composition and intrusion effects to other rock bodies recognized as igneous intrusions. The presence of a slightly greater amount of certain substances, the so-called mineralizers, has probably caused the unique texture. But their amount is very small compared to the entire rock bulk. It seems perfectly justifiable then, of choosing between the terms vein and dike, to refer to the California pegmatites as dikes. Bastin[38] continuously speaks of pegmatite "magmas" and in regard to Streaked Mountain in Hebron, Maine, says: "it is difficult to conceive of a mass of this size and general uniformity crystallizing under anything like vein conditions." Moreover he concludes (p. 39) that "It is probable, therefore, that the whole mass of many of the coarser pegmatites crystallized not far from the inversion point of quartz; that is, not far from 575°C"

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[37] Bastin, E.S., Geology of the pegmatites and associated rocks of Maine: Bull. 445, U.S. Geol. Survey, p. 33, 1911.

[38] loc-cit., p. 35

.Such a temperature is not compatible with vein formation from a water solution whose critical temperature is several hundred degrees lower.

Part III. The lithium-bearing pegmatite mines and prospects of southern California and selected world localities

San Diego County

Pala

Pala is situated on San Luis Rey River, in the northwestern part of San Diego County, about 25 miles east of the Pacific coast line, and its altitude is about 400 feet. High hills and mountains surround Pala on all sides, and lying east and northeast is the rugged mass best known locally as Smith's Mountain, which reaches an altitude of 6,000 feet. In fact, Pala may be said to lie in the western foothills of Smith's Mountain.

The three hills to the northeast of Pala are the only ones in this vicinity on which any lithium minerals have so far been found, and for convenience in reference they have been named, beginning with the westernmost, Stewart Hill, Pala Chief Hill, and Hiriart Hill. Considerable prospecting has taken place on all three of these hills in recent years and the presence of at least 70 distinct masses of pegmatite has been shown. Most of the outcroppings are on the slope of a hill and it is sometimes impossible to decide whether a given mass of pegmatite is the outcropping of a ledge in place or whether it has broken off from the parent ledge higher up the hill and has slid down to its present position.

The topography and the general geology of the region northeast of Pala can be seen on the accompanying map, Plate XIV. The large contour interval (100 feet) on the only available map makes the exact location of the mines and prospects somewhat uncertain. The country surrounding the producing mines has been laid off in claims, on which very little work has been done as a general thing.

The general geology of the region is simple. The valley shown in the lower part of Plate XIV is detrital matter composed of sand, gravel, and huge boulders. The northern part of the map shows an extensive body of granite, which extends farther north for many miles. On its southern side this granite has been intruded by gabbro, which now forms the three hills on which the gem mines are situated. It is particularly interesting to note the large number of pegmatite bodies found, as shown in Plate XIV. Three minor points of the geology of this region are not shown on the map (Pl. XIV). These are a small granite area on the western side of Stewart Hill; a rock a short distance south of the Pala Chief mine, which seemed to be different from the gabbro; and some small pieces of a quartz-augite rock, resembling hornstone, on Hiriart Hill.

A cross section view of the three hills mentioned, following the irregular line AB-BC-CD-DE- EF of Plate XIV, is shown in figure 17 from which the general uniformity of the dip of the pegmatite dikes can be seen.

Figure 17. Cross section at Pala. A-F of Plate XIV.

Occurrences on Stewart Hill

Stewart mine and immediate vicinity.

The Stewart mine is one of the first mines to be developed and is in many ways

the most interesting mineral deposit of the region. It is located near the southern end of one of the largest lithium-bearing pegmatite dikes known in the entire gem-tourmaline field. The dike is three quarters of a mile long and has a maximum thickness, at the mine, of at least 60 feet. The northern end of the dike is much thinner and pinches out near the contact of the gabbro and the granite. (See Pl. XV) Near the middle, the dike is apparently divided into two parts, for a tunnel driven in here passes through pegmatite for a short distance, then through altered gabbro, and then into pegmatite again, which had not been pierced in 1904. The surface appearance also indicates a subdivision of the dike. The southern end, just below the Stewart mine, terminates irregularly, as shown in figure 18, and may be the result of a fault; part of the dike has dropped a short distance, leaving the present extreme western end in its original position.39 This western end also is much thinner than the main dike and pinches out as the northern end does. Faulting, though rare, does occur in these rocks, as a very clear example was seen at Mesa Grande (Pl. II B). In the lower tunnel near the southern end of the dike (fig. 18) several narrow stringers of pegmatite intrude the gabbro. A shaft sunk between the main dike and its extreme western end went through gabbro for 15 feet and then after a distance of 40 feet struck pegmatite that had not been penetrated.

The dike dips westward at a low rate, the angle of contact with the gabbro being less than 20° and measurements at three different places giving angles of 12°, 12°, and 17°. A good view of the dike, on which at least nine other prospects have been developed, is afforded by Plate XV, which shows the entire eastern side of Stewart Hill.

Most of the pegmatite at the Stewart mine is very coarse grained. Graphic granite occurs abundantly in large masses but does not form the entire dike. Large bodies, many feet thick, of pure quartz40 and of nearly pure feldspar abound. Shattered black tourmalines, several inches thick and several feet long, are not rare. Muscovite is nowhere very plentiful but is found in many parts of the pegmatite, at places forming small scaly aggregates. Fine-grained pegmatite is occasionally found but does not constitute a continuous formation.

Lithium minerals, chiefly lepidolite and pink tourmaline, appear in very small quantity throughout the greater extent of the dike but are concentrated in its southern part. They are separated from the extreme southern boundary of the dike (a possible fault line) by at least 150 feet of normal pegmatite apparently free from any lithium minerals.

The lithium minerals at the Stewart mine are not confined to a single mass but, as exposed by the mining operations, form one large body, more than 100 feet thick, and six smaller bodies (fig. 18). One of the smaller bodies, now extracted, consisted of amblygonite; the others are composed of lepidolite. It has been the experience of the miners that the large bodies of lithium minerals were surrounded by very much smaller bodies of the same mineral embedded in the ordinary pegmatite. The essential minerals of the pegmatite are not heterogeneously mixed together but occur in separate and distinct bodies often consisting of nearly the pure mineral. The positions of the bodies of lithium minerals at the Stewart mine are shown in figure 18.

Figure 18 Plan of Stewart mine and immediate vicinity, Pala. The shaded areas

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[39] The large scale (100 foot) of the only available topographic map of the region renders such determinations almost impossible. The irregular broad end of the pegmatite outcrop as shown in figure 18 is different from the known ending of any of the other ledges of this region.

[40] A body of pure quartz, shown in figure 19, has a thickness of about x? feet.

represent lithium minerals.

Figure 19 Plan of mineral relations, Stewart mine, Pala.

Figure 20 Cross section of mineral relations, Stewart mine, Pala.

A more detailed plan of the minerals encountered in the workings of the Stewart mine is shown in figure 19, and the same relations in cross section in figure 20.

The first work that was done on the Stewart mine was on the outcrop of the largest lepidolite body in the dike, which has been extensively developed, though no work has been done on it in recent years. Viewed from the eastern entrance of the main tunnel as shown in Plate XVI A the lepidolite body seems to have a lens shape, pitching toward the south. In the direction of the pitch the entire lens is about 90 feet long and reaches a maximum thickness of about 20 feet. It has been tunneled for 120 feet and the length of the lens in this direction when first exploited was nearly 200 feet. The lens extends past the tunnel on the south side for only a few feet, when it pinches out. A short distance from the entrance of the tunnel a small drift was dug in the pegmatite on the south side. At the end of this small drift, a shaft, now filled in, was dug down about 18 feet (shown in figure 18) without finding any lepidolite. On drifting back and up a few feet the edge of the lepidolite lens was struck. The extreme southern end of the lens is very wavy and the main tunnel following the edge of the lens is, in consequence, rather wavy and irregular. The massive lepidolite just across from this small drift is shown in Plate XVI B. At this place the rock consists of compact lepidolite with a very small percentage of other minerals, mostly pink tourmaline. It is from this portion of the lens that the well known lepidolite and rubellite specimens (see Plate XXXIII) have been obtained. Most of the rock is purer lepidolite than the specimen illustrated.

The body of lepidolite forming the extreme southern end of the lens (shown in Plate xyz) is fine-grained and of a whitish color, though a faint purple tinge is usually present. The finer the grain, the purer and more valuable is the ore. The following is an analysis made by the writer in the survey laboratory of a selected sample of the ordinary whitish lepidolite such as is mined. Care was taken to obtain a pure sample of the mineral, and the analysis therefore does not give an accurate idea of the lithium content of the ore, which would be somewhat smaller than the value here given.

Analysis of lepidolite from Stewart mine, Pala, California.
W. T. Schaller, analyst.

Silica (SiO_2)	51.25
Alumina (Al_2O_3)	25.62
Iron Oxide (Fe_2O_3)	.12
Manganese oxide (MnO)	.05
Lime (CaO)	Trace
Magnesia (MgO)	None
Lithia (Li_2O)	4.31
Potash (K_2O)	10.65
Soda (Na_2O)	1.94
Water (H_2O)	1.60
Fluorine (F)	7.06
	102.60
Minus oxygen equivalent to fluorine	2.97
	99.63

89

Wherever the edge of the lens is exposed, the partly decomposed pegmatite surrounding the lepidolite contains much kaolin, halloysite (pink clay), and more or less decomposed feldspar, as well as fresh feldspar, quartz, tourmaline, and lepidolite. A drift on the north side of the tunnel penetrates the lepidolite lens for about 80 feet. At this place the rock, as exposed by several small drifts, consists of a mixture of lepidolite, feldspar, quartz, and pink tourmaline, of which the lepidolite docs not constitute more than half.

The western end of the lens dips steeply toward the south and the tunnel following it slopes down for a vertical distance of 13 feet. Next to the lepidolite lens is normal pegmatite and beyond it is a body of massive quartz. About 20 feet beyond the end of the lepidolite lens was encountered the edge of the main mass of amblygonite. Several small nodules of amblygonite were encountered in the pegmatite between the main mass and the lepidolite lens. This is the extent to which the mine was developed up to June, 1903.

The west tunnel, 110 feet long, with its several drifts, is the result of work done between June, 1903, and June, 1904. Close to the mouth of the tunnel was found a considerable quantity of lithiophilite, largely altered to numerous secondary minerals described on page xyz. A short distance away a small mass of lepidolite, several feet thick, encountered and 20 feet farther a much larger body of lepidolite was found and extracted. Only a few feet from this larger lepidolite body but separated there from by normal pegmatite and by massive quartz, lay the main mass of amblygonite, which had been reached the previous year by the older tunnel. The last drift of the west tunnel is in massive, nearly pure quartz and at the end of the tunnel lepidolite was again met with, doubtless the western part of the main lens already described.

As the lepidolite occurs in a solid mass and as the nearly pure mineral is concentrated at one end of the lens, it was taken out and shipped without any further treatment. The dike has a very low dip (about 15°) and the lens dips at a low angle toward the south, hence the occurrence is very favorable for mining at small expense. No hoisting of the ore is necessary, that occurring at the southwestern end of the lens being taken out by way of the western tunnel. But little foreign or dead material has to be removed. The ore is blasted loose, piled into cars, and brought by either tunnel to the surface; here it is rolled down the hill to a level road, then it is hauled by team to the railroad at Fallbrook.

The amblygonite occurs massive in a pure state, showing cleavage faces several inches across. The main mass of amblygonite as well as the smaller nodules were surrounded by massive quartz, which is very thick at paces. In this quartz several pounds of native bismuth and its alteration products (described on pp.) have been found.

The main mass of amblygonite has a lens shape, pitches to the south, and seems to parallel the lepidolite lens in shape and position. In June, 1904, it had an exposed length (north and south) of 25 feet, ·with a width (east and west) of 12 feet and a thickness of at least 14 feet. The entire body was not exposed then and later work showed that the mass was considerably larger than the dimensions given. The amblygonite strongly resembles orthoclase for which it was at first mistaken. The miners became so expert in handling it that they could readily distinguish it from feldspar by its weight alone, amblygonite having a specific gravity of 3.1and feldspar of 2.57. The mineral as found is usually very pure; occasionally small quantities of quartz and lepidolite are associated with it.

An analysis was made on a selected sample, which was first examined microscopically and found to be pure. The analysis is shown below.

Analysis of amblygonite
from Stewart mine, Pala, California.
W.T. Schaller, analyst

Phosphoric Anhydride (P_2O_5)	48.83
Alumina (Al_2O_3)	33.70
Iron Oxide (Fe_2O_3)	.12
Manganese Oxide (MnO)	.09
Magnesia (MgO)	.31
Lithia (Li_2O)	9.88
Soda (Na_2O)	.14
Water (H_2O)	5.95
Fluorine (F)	2.29
	101.31
Less oxygen (O) for fluorine (F)	.96
	100.35

Amblygonite contains about twice as much lithia as lepidolite and is therefore a much more valuable ore, as the cost of extracting the lithia is the same.

Transparent tourmalines have occasionally been found in the Stewart mine, but they were too small to be of much value. A few crystals clear pink, yellowish-green, or pale green in color and large enough to be cut were found in pockets in the coarse pegmatite at the mouth of the western tunnel.

A long tunnel was driven through the gabbro below the main tunnel of the mine but up to May, 1909, pegmatite had not been reached.

The size and extent of the lepidolite found at the end of the upper tunnel (fig.) is not known for it has not been prospected. Several hundred pounds of lepidolite were taken out and in 1903 a small quantity lay on the dump. The lepidolite contains much rubellite in small crystals and some quartz and feldspar; these lower the percentage of lithium in the rock to a figure commercially worthless. The presence of so much tourmaline would also considerably increase the cost of crushing.

About 65 feet south of the main entrance to the Stewart mine exposed by a small open cut 10 feet long and 5 feet wide is a small body of lepidolite about 10 feet thick. The bluish-purple mica is present in only small quantity and the lepidolite is not nearly so pure as that of the Stewart mine, for it contains considerable quartz and feldspar. The body of mica grades into pegmatite, free of lepidolite, there being an intermediate rock composed of a little lepidolite and much quartz and feldspar between the true pegmatite and the main body of mica. The speckled lepidolite-feldspar rock makes exceedingly pretty specimens.

On an adjoining claim, known locally as "The Forty", being the original tract of 40 acres located for the lithia mine and above the lower tunnel (fig.). There is a small body of lepidolite a few feet thick and dipping towards the south. It has been exposed by a small open cut. The quantity of lepidolite present is small. It is fine-grained, of a purple color, and contains more or less pink tourmaline, feldspar, and quartz. An

analysis of this lepidolite is given on page

Tourmaline Queen Mine

The Tourmaline Queen mine lies on the eastern side of Stewart Hill near its summit and is about a mile north of the Stewart mine. A distant view of the mine and of the pegmatite dike on which it is situated can be seen in Plate XV.

Plate XV. View looking west of Stewart Hill, 1909. Stewart (1), Lobaugh (2) and Tourmaline Queen (3) mines shown below the numbers.

The uppermost dike on Stewart Hill is the one in question and the workings farthest north represent the Tourmaline Queen mine. Another view of part of this mine is in Plate IV A, which however, shows the character of the outcropping pegmatite rather than the mine itself.

The large pegmatite dike dips toward the west at a low angle and two open cuts have been worked on it, the one toward the south being known as the lower cut and the one towards the north as the upper cut. At the lower cut, the surface rock has been blasted back for 35 feet and two dikes have been exposed; only the upper one contains any lithium minerals. The relations are diagrammatically shown in figure 21.

Figure 21 Diagrammatic sketch of pegmatite, Tourmaline Queen mine, Pala.

The upper ledge is about 4 feet thick; the space between the two ledges varies; but in general is a little less than 4 feet. This upper ledge a typical example of the first group of pegmatites as previously described (p.), consists of a coarse aggregate of feldspar, quartz, mica, garnet, and tourmaline (black) and in the center is the narrow pay shoot, containing the gem and lithium minerals.

A thin section of a specimen from this upper ledge showed predominant quartz and indigo-blue tourmaline and also a little garnet, orthoclase, and muscovite. The garnet is allotromorphic and seems to have been attacked and partly dissolved, the materials present in the attacking medium furnishing the necessary ingredients to form, with those derived from the garnet, pale-blue tourmaline. Many rounded small particles of garnet can be seen in the midst of the irregularly bounded tourmaline

areas.

Much of the tourmaline, however, is distinctly primary and shows a strongly marked zonal development in its color, which generally, but not always, becomes lighter from the center. The quartz, garnet, and secondary tourmaline are full of bands of bubbles.

The lower ledge consists of an upper graphic-granite part and a lower fine-grained part, but without any lithium minerals. The two parts are of equal thickness, about 9 feet. The extreme upper edge is medium-grained graphic granite containing some biotite. The main mass of the graphic granite as revealed in thin section consists of intergrown feldspar and quartz and but very little muscovite and garnet. The feldspar did not show a trace of the grating structure of microcline and seems to consist almost entirely of orthoclase, unless perchance barbierite, the soda equivalent of orthoclase, should be present. Albite is absent. Just above the center of the ledge, the lower portion of the upper part loses its graphic structure and becomes very coarse grained, large masses of quartz, feldspar, and mica being present. The lower half of the ledge is of a coarser grain than usual and is free from any banded arrangement of any of its constituents. It often contains, however, horizontal layers of the same minerals more coarsely crystallized. A study of a think section showed the rock to be composed of quartz, orthoclase, muscovite, garnet (idiomorphic), and a very little albite.

At the upper or northern cut, developed by open cuts and short tunnels, what seems to be the same as the upper dike in the lower cut has increased in size to 15-20 feet. There are here the normal conditions, an upper graphic granite part, a lower fine-grained part, and in between the coarse pay shoot carrying lithium minerals. The upper graphic granite contains many large black tourmalines, large masses of pure feldspar and quartz, and also intergrowths of garnet and quartz, tourmaline and quartz, muscovite and quartz. Lepidolite and pink tourmalines are abundant in the pay shoot and show various gradations in color. Tourmaline is the only mineral of value found here and has been produced in considerable quantity; clear stones occur in various shades and colors, as well as stones of more than one color.

Tourmaline King Mine

On the northern and northwestern side of Stewart Hill near its summit is a large pegmatite dike that apparently pinches out near its upper end. A short distance below, two small open cuts show that the dike has here a thickness of 3 feet. Lower down the hill the dike is much wider, reaching a thickness of at least 15 feet. Here six tunnels have been driven at different places. The pegmatite is a coarse-grained rock, often consisting of graphic granite throughout. Where the bottom of the dike is exposed, no fine-grained "bottom rock" is seen. The pay shoot, near the middle of the pegmatite, is in places very rich in tourmalines. The dike dips to the southwest at a low angle.

Prospects on Stewart Hill

Of the large number of prospects on Stewart Hill, only those to which some particular interest is attached will be described. Besides the workings already given under the mine descriptions, a total of 43 prospects were visited on Stewart Hill. The approximate position of such of these as are here mentioned can be seen by reference to the map (Pl. XIV). Prospect No. 16, below the Tourmaline Queen Mine, is on a large pegmatite dike, which outcrops a short distance below the

contact of the gabbro with the granite. The entire pegmatite consists of coarse graphic granite, without any fine-grained lower rock. No lithium minerals were seen in it.

Several prospects (Nos. 20, 21, 22, and 23) lie on the same ledge as the Tourmaline Queen mine, but no minerals of value seem to have been found. Along the trail on the western side of Stewart Hill from the Tourmaline King mine to Pala at least four, large pegmatite dikes are passed before the bottom of the hill was reached. No work has been done on them.

On the side of Stewart Hill facing Pala numerous pegmatite dikes appear. Prospect No. 36 is one; it has an ex-posed thickness of 7 feet but is probably much thicker, and it pitches westward at a low angle. The ledge shows the coarse upper part and a finer-grained lower rock containing considerable biotite. The differences between the upper and the lower parts are not typical and the presence of considerable biotite in the lower finer-grained rock is unusual. A small tunnel about 10 feet long has been developed, but no indication of lithium or gem minerals could be seen.

Prospect No. 37 lies about No. 36 and consists of a small open cut on a pegmatite dike varying from 2 to 3 feet in thickness and pitching westward at a low angle. At one place the dike shows a coarsely crystallized streak, with coarse granite (finer than the coarse streak) above and a fine-grained rock below. This lower fine-grained rock is not banded and resembles that at the Tourmaline Queen mine. At a different part of the dike, however, the entire mass is uniformly a coarse pegmatite rock. The transition between the two parts could not be seen as it was covered up by soil. Between Numbers 36 and 37 is a mass of coarse pegmatite, at least 7 feet thick, with many muscovite-quartz and garnet- quartz intergrowths.

Prospect No. 38, a short distance above No. 37, is a small open cut made on a dike from 2 to 3 feet thick. The coarse pegmatite seems to have a biotite granite as its lower part. Halfway up to prospect No. 35 is the outcropping of a large dike, apparently many feet thick, but no prospecting has been done on it. Some of these outcroppings so resemble a small granite intrusive mass that it is difficult to say whether there has been a granitic intrusion into the gabbro or whether the rock is only the lower fine-grained part of a pegmatite mass.

Prospect No. 35 consists of an open cut about 15 feet long, and at its end a 30-foot tunnel runs into a large pegmatite dike, more than 25 feet thick. The pegmatite dike seems to resemble that of the Stewart mine in that the fine-grained bottom rock is not continuous, but occurs only in places. The upper part consists of large masses of pure quartz or of feldspar and contains large black tourmalines. Graphic granite is abundant but does not form the entire rock. A striking peculiarity of this dike is that near its middle there is a band 20 inches thick of alternating layers of gray quartz and white feldspar, each layer averaging about an inch in thickness but varying considerably. The layers usually crack in the middle of the feldspar layer and seem to lie parallel with the dip of the entire dike. In the lower part of the dike, the rock cleaves with a smooth surface parallel to the surface of the layers above described. The uppermost layer of the 20-inch band is feldspar; above this comes a layer one-quarter to one-half inch thick of plumose muscovite; and above this a layer 18 inches thick of massive quartz. A free-hand sketch of the center part of this ledge is shown in figure 22.

Figure 22 Diagrammatic sketch of pegmatite, Prospect No. 35, Pala. Shows the band of alternating layers of quartz and feldspar.

Prospect No. 39 contains a tunnel in the gabbro about 40 feet long. By following a pegmatite dike until it pinches out, the variation in thickness of the dike appears plainly, such irregularity in thickness being most unusual for these dikes. At the surface, near the north of the tunnel, the ledge is about *5* feet thick but it rapidly thins and, after a slight bulge, pinches out 20 feet from the mouth of the tunnel. These relations are shown in figure 3 on page xyz.

Prospect No. 44 is on a pegmatite dike about *5* feet thick, pitching westward at a steep angle. The dike consists of coarse pegmatite with a fine-grained border, 3 inches thick, at the top and at the bottom. Below the top border is a layer of garnet. A tunnel follows the dike into the hill for about 35 feet. Lepidolite, albite, blue tourmaline, and many large quartz crystals appear on the dump.

Prospect No. 45, just below No. 44 and probably on the same ledge, shows a coarse pegmatite *5* feet thick, through which runs a 2-inch band of garnets. Lepidolite was noted on the dump.

The prospects described below are all on the same pegmatite dike as the Stewart mine.

Prospect No. 55 has two tunnels following the dike. The rock is very similar to that at the Stewart mine. Much pink clay (altered tourmaline) and partly altered pink tourmaline, as well as a coarse-grained purple lepidolite, are present. Kunzite in small pieces is also reported. At prospect No. 57, the tunnel shows the dike to consist mostly of graphic granite. Prospect No. 60 follows the dike for a considerable distance by two tunnels. The lower part of the dike, here well exposed, consists of a fine-grained but not banded rock. This is microscopically to consist of a granitic rock composed of albite, orthoclase, quartz, muscovite, and a few, often irregularly shaped, masses of garnet and tourmaline. The upper part of the dike is graphic granite. At the center are occasionally seen alternations of small layers of the upper and the lower parts. A few feet away is an open cut where the upper part of the dike is again seen to consist largely of graphic granite. Prospect No. 63 shows considerable biotite.

Prospect No. 76 shows the upper part of the dike to consist of a coarse rock which frequently forms graphic granite and is about 7 feet thick. The lower part of the dike, only 2-1/2 feet thick, is a fine-grained rock without any banded structure. At the center, for about a foot in thickness, there are several alternations of the upper coarse and the lower fine-grained rock, the layers being several inches thick. A little biotite occurs at the bottom of the upper part. These features are illustrated diagrammatically in figure 23.

Figure 23. Pegmatite at prospect No. 76, Stewart Hill, Pala. Shows alternations of upper and lower parts

Prospect No. 72 is at the northern end of the small dike lying below and paralleling the larger dike on which the Stewart mine is located. The dike at prospect No. 72 is 32 inches thick and is divided into two parts by a sharply defined crack in the center. The lower part is not fine grained, however, as the entire ledge consists of a medium-grained graphic granite of fairly uniform texture. About 2 inches from the top is a little biotite. The relations are shown diagrammatically in figure 24.

Figure 24. Pegmatite at prospect No. 72, Stewart Hill, Pala. The pegmatite is uniformly fine-grained graphic granite

Occurrences on Pala Chief Hill

Pala Chief Mine.

Pala Chief Hill, on the top of which are the workings of the Pala Chief mine has a large number of pegmatite exposures, and it is difficult to determine which of these pegmatite dikes are in place and which have slid down the hill after having broken off from the parent dike.

The dike on which the Pala Chief mine is located forms a blanket on part of the western side of the hill top and extends downward along the slope for some distance. At the top of the hill the entire dike outcrops and is seen to consist of two distinct parts, an upper coarse pegmatite, mostly graphic granite, and a lower fine-grained banded rock, the wavy irregular bands of color which give the banded appearance being due to small garnets. Between these two parts or, more accurately, in the lower part of the upper coarse pegmatite, is the pay shoot, rich in gems and lithium minerals, of which the lilac spodumene, kunzite, has made this mine famous. Plate X, B, taken by Prof. A.C. Lawson, of the University of California in 1903, gives a good view of the mine and shows also the division of the dike into the upper and lower parts. The mine has been developed by open cuts, the main one of which has followed the dike for over 300 feet and has dug down on it to a depth of nearly 30 feet, the open cut often being 5 feet wide. In places, the dike seems to be nearly 20 feet thick, though this is probably a maximum.

The upper part of the dike, from 6 to 10 feet thick, consists of graphic granite of varying degrees of texture. In this are sometimes found small (rarely over a few inches wide) later pegmatitic veins consisting of orthoclase, quartz, and muscovite, but containing no lithium minerals. The lower part of the dike not banded throughout, averages 2 or 3 feet, but sometimes reaches a thickness of 5 feet. The middle part with its pay shoot varies considerably in thickness, from 3 inches to 3 feet, but averages about 2 feet, and is much shattered and broken and in places very soft and crumbly. Black tourmalines, many of immense size, are found in the graphic granite and are usually vertical and just above the pay shoot, and are said to point, in general, toward a pocket in the pay shoot. The presence of a mass of minute blue tourmalines is also considered a good sign for the presence of a pocket. Muscovite is not abundant in the graphic granite and, when present, forms plumose masses with quartz; the muscovite in the pay streak forms wedge-shaped crystals. It was at first believed that the gem tourmaline and spodumene would never be found in the same pocket but the minerals have been found together. The gems found here in quantity are tourmaline and spodumene, most of the kunzite (lilac-spodumene) found being obtained from this mine.

Gem tourmalines are abundant in the pay shoot as small, transparent crystals of various colors, and more rarely as large magnificent crystals (Plate xyz). Blue tourmaline (indicolite) are characteristic of this mine and frequently have a pink core and vary in size, becoming at times very large, the largest one found being reported as about 7 inches long and 4 inches thick. Small indicolites frequently occur in quartz crystals and pink crystals are often imbedded in a mass of pink lepidolite.

Spodumene occurs here in great perfection and in large size for the transparent variety. The crystals are usually flat, the ends being rounded and the flat surfaces deeply furrowed vertically. The crystals are clear and transparent and are found pink, lilac, colorless, and pale green in color. Compare Plate xyz.

The occurrence of this Pala Chief spodumene, especially the lilac, is of the greatest interest. Spodumene of similar pink color from Connecticut had been

described by Brush and Dana in 1880, and a description of this occurrence is briefly given on p.) The transparent Connecticut spodumene has not, however, had any commercial production. Pink transparent spodumene is also found in Madagascar (see p.). Very pale-green spodumene has also been found here. It is a very pale variety of the hiddenite found in North Carolina (see p) at about the same time that the Branchville, Connecticut, discovery was made.

The spodumene usually occurs at the Pala Chief mine loose in the pockets, but a few specimens have been found in which it is enclosed in quartz crystals and also in the pegmatite which shows that the mineral is undoubtedly an original constituent of the pegmatite. In fact, it seems that it was among the very first to crystallize out; it preceded the feldspar, quartz, and mica. If this be true, it is remarkable that the mineral should have withstood alteration so long, for though a small quantity of it has undergone decomposition, most of it is entirely fresh, though very much etched. The transparent condition of these spodumene crystals, coupled with their remarkable etching, furnishes a valuable criterion for a discussion of the formation of these pegmatites and their constituent minerals, which is developed in the description of the spodumene given on pp. to . The spodumene occurring a mile to the east on Hiriart Hill is much more altered, and that from Connecticut described by Brush and Dana is almost completely altered. A chemical analysis shows that the composition of the pink spodumene from the Pala Chief mine is entirely normal and very similar to the composition of the pink spodumene from Connecticut.

The associated feldspar occurs in rude crystals and the abundant quartz frequently occurs as large crystals and groups of crystals a foot or more in length. Some of the crystals found here are of immense size and many of the smaller ones have a peculiar enameled appearance. Smoky quartz is frequent. Muscovite is not very abundant and occurs in small scales, sometimes with a pinkish cast. Albite is present, though not in great abundance, in tabular crystals and in masses. Beryl of a pink color has been obtained, and golden beryl has also been reported as found here. Lepidolite is fairly abundant and occurs in large masses of a red-purple color and in scales having a diameter of several millimeters.

Prospects on Pala Chief Hill

Prospect No. 13, on the western side of the hill, reveals an interesting set of relations though possibly not all the rocks are in their original position. In an open cut about 12 feet long and 10 feet deep, a pegmatite dike 3 feet thick lies near the surface, and abutting this is a smaller one, 19 inches thick, which in turn is met by a still smaller one 8 inches thick. Besides these a bunch of 8 stringers none of them more than an inch thick lay in 3-1/2 feet of gabbro in approximately parallel position to the smaller dikes mentioned above. A single stringer, the ninth, was from 2 to 3 inches thick, bulging out, however, to 8 inches. There is apparently here a group of pegmatitic dikes whose relations to one another are probably very complicated. Though similar in general character, they differ from one another in detail. The largest dike consists of two parts, each 18 inches thick. The upper part is a coarse aggregate of quartz, feldspar, mica, and black tourmaline-which do not, however, graphic granite-and resembles the pegmatite described as typical of the first group. The lower part is a fine- grained graphic granite having brown garnets, blue-black tourmaline, and a little muscovite sprinkled throughout the rock. Under the microscope a thin section reveals the graphic intergrowth of microcline with quartz and the presence of small amounts of albite, orthoclase, muscovite, garnet, and tourmaline. In the fact that this dike has graphic granite throughout the lower half but not in the entire upper half, it is different

from all the others examined. The medium-sized ledge (19 inches thick, Specimen No. 402) is a fine-grained rock having a slightly developed gneissic structure, which is also shown in thin section where the prominent minerals are seen to be quartz, orthoclase, microcline, albite, and biotite. The small 8-inch ledge is a coarse quartz and feldspar pegmatite, not showing any graphic structure, and carrying garnet and biotite. The feldspar is microcline. The largest of the stringers is a medium to fine grained aggregate of quartz and feldspar with much secondary biotite. The small stringers consist of a quartz-feldspar aggregate without biotite. Prospect No. 2 is on a large dike that shows the coarse graphic-granite upper part and a finer- grained lower part. The dike, probably 8 feet thick, does not present a clear division into the two parts. Numerous quartz and feldspar crystals occur near the middle. Prospect No. 3 is on a dike at least 8 feet thick and irregular in size, but apparently a flat lying body. The upper 5 feet contains masses of feldspar 2 feet thick, graphic granite in abundance, also radiating masses of muscovite, and a layer of black tourmaline several inches thick. The lower part is finer grained and generally not banded. The extreme bottom of the dike contains bands of garnet which have largely decomposed, and the rock is stained black by separated manganese oxide.

Blue beryl is reported as having been found in Prospect No. 65. Prospects Nos. 15, 9, 10, 11, 16, and 67 are all on a large flat-lying dike having a coarse upper rock 2 to 3 feet thick and a lower, fine-grained, often banded rock of similar thickness. A well-defined layer of pockets occurs in the middle, and these pockets have yielded large crystal of quartz and feldspar, as well as albite, lepidolite, pink beryl, and some gem tourmalines.

Prospect No. 68 is a small open cut with a 20-foot tunnel which branches west for about 10 feet. The dike, about *5* feet thick at the mouth of the tunnel, shows a coarse upper and a banded fine- grained lower rock. A central pay shoot is full of transparent quartz crystals. At the end of the tunnel, the ledge is only 2 feet thick and becomes a uniform mass, the pay shoot having disappeared. No lithium minerals have been found here. A greenish mica was supposed to contain lithium, but tests show it to be lithium-free muscovite.

Occurrences on Hiriart Hill

Hiriart Hill is the most easterly of the three lithium-bearing hills at Pala. The summit is about 1,750 feet above sea level, or 1,200-1,300 feet above the general level of the valley at Pala, though from the foot of the hill to the summit is only about 1,000 feet. The hill is roughly cone-shaped except on the eastern side, where a saddle at an elevation of 1,650 feet above sea level connects ·with another hill. The trail from the main road from Pala winds around the western and northern sides of the hill and reaches the above-mentioned saddle near the contact of the gabbro with the granite.

A striking feature of this hill is the number of prominent pegmatite dikes which traverse it, about 25 in all. (Plate XIV). Their outcrops have a more or less crescent-shaped arrangement due to the shape of the hill and, in general, they dip northwest. The dikes vary in thickness from a few feet to at least 30 feet. Small stringers of pegmatites, intrusive in the gabbro, are common at places. Claims cover almost the entire hill, which has been fairly well prospected in the search for gems.

The San Pedro is the dominant pegmatite dike, and extends almost entirely around the hill. On it are located the principal mines of Hiriart Hill, namely, the Katerina, the Naylor-Vanderburg, and the San Pedro. The Hiriart mine is on a different dike and is below the Katerina.

The pegmatite dikes show admirably the division into an upper coarse

pegmatite rock and a lower finer-grained, banded rock. At some places tourmalines form the wavy bands that traverse the lower half of the dike. At two places the under surface of the upper half of the dike was apparently pitted by corrosion, for the rock surface was covered with inverted depressions. At one part of a dike a large body of massive quartz several feet thick occupies the space between the upper and the lower parts of the dike. This last feature is illustrated in Plate XVII A. Where a section of the entire ledge is broken, the line of breakage is generally along the pay shoot, usually a few inches above the lower banded rock (Pl. XVII B.). The dikes usually reach their coarsest development along this central line, in which cavities are very frequent and which thus becomes a line of weakness and of fracture.

Lithium minerals have been obtained from nearly all of the dikes, from some only in small quantity. Lepidolite is very common; tourmalines (blue and green) and beryls (colorless and pink) have been found at several places; and spodumene occurs as float more or less over the entire hill.

Katerina mine

The Katerina mine is near the west end of the big dike which forms the dominant pegmatite mass of Hiriart Hill and dips about 30°W. The main workings in 1909 consisted of large open cuts, an inclined tunnel 30 feet long, and a small drift. The pay shoot of the middle part is generally several feet thick; the development at this time shows in places a thickness of 8 feet. The minerals above the pockets in the pay shoot are in some places in more or less distinct layers. Immediately above the pockets is massive quartz followed, respectively, by a layer of albite, of orthoclase, and finally of mica. Many of the pockets are rounded and surrounded by massive quartz in curved platy masses. The pay shoot as seen in 1909 contained an unusually large quantity of altered spodumene crystals, many more than a foot long and one 3 feet long. (Plate XVIII B). Some fresh clear spodumene of good lilac color was also embedded in the altered mineral, which was changed to a deep red clay. If this alteration of the spodumene is a surface weathering phenomenon, then a considerable amount of good material should be found when the developments are more extended. It is believed, however, that this alteration is due to magmatic changes which took place before the whole dike had solidified (see p.   ). Small compact masses of minute blue tourmaline often form patches on the sides of pieces of the pegmatite, either as a thin covering or as small stains. They seem to have been deposited on the wall.:; of a crevice.

Spodumene, tourmaline, lepidolite, and amblygonite have been found in this mine. The deep- purple spodumene is more abundant that the pale-pink variety. Recent developments have exposed a quantity of white and fine-grained lepidolite, similar to that occurring at the Stewart mine, and several tons of it have been taken out in prospecting. The massive amblygonite occurs in large nodules. It is white, and at times shows a tendency to become transparent.

Naylor-Vanderburg mine.

On the same pegmatite dike with the Katerina extensive workings are located near the summit of the hill on the boundary line of the Naylor and the Vanderburg claims. The workings are represented by a large open cut and a tunnel nearly 200 feet long, cut below the outcrop of the ledge but striking it at its end. The dike seems to be more than 30 feet thick and dips westward at a steeper angle than at the other

mines. The large open cut has exposed the lower banded rock, which is colored black by manganese oxide stains resulting from the decomposition of the garnets.

The pocket matter found in the pay shoot consists of loose small fragments of rock and of isolated crystals covered and mixed with dry fine clay. When a pocket is opened, the pocket matter falls out like grain from a chute. An examination shows it to consist of pegmatite rock, feldspar, quartz crystals, muscovite, and lepidolite, ·with smaller quantities of garnet, tourmaline (red, blue, and green), beryl (colorless and pink), and spodumene (lilac). The valuable gem minerals are not present in every pocket, whereas other pockets contain large quantities of minerals valuable for their gem qualities.

Spodumene of good color has been found, both in the open cut and at the end of the tunnel. Some of the deeply colored and perfectly clear crystals weighed a pound (See Pl. VIII). A number of specimens showing the alteration of the spodumene were found here. They are of a pale-lilac color, but opaque, and show gradations in the alteration to an end product consisting of a lilac colored day. The form, striations, and cleavage of the spodumene are retained by the clayey masses. These are described on page xx. Nodules of montebrasite as large as a man's fist occur scattered through the pegmatite.

San Pedro mine

The San Pedro mine, from which spodumene, tourmaline, and beryl, all of gem value, have been obtained, is of interest chiefly on account of the good exposures of the pegmatite dike which, allow its structure to be well seen. Some of these features were photographed and are reproduced in this report. An open cut shows that the dike consists of the usual upper and lower parts, with the middle part containing the pay shoot in between. Plate X A, page   , shows a view of the dike, in which the lower banded rock, at least 15 feet thick, can be seen. The bands do not everywhere extend all the way down, the remainder of the dike being finer-grained but not banded. The cavities just above the top of this banded rock are pockets in the pay shoot of the middle part. In parts of the dike, several alternations of coarse pegmatite with the fine grained rock occur. There are about three of these alternations, one of which is a foot thick. Some of the coarse pegmatitic layers are in the graphic granite, others are in the banded rock. Just above the pay shoot of the middle part are large masses of quartz, feldspar, and mica, the feldspar often in imperfect crystals. In this coarse aggregate are numerous large black tourmalines, nearly vertical in position, which are said to pint to pockets in the pay shoot, especially if the black tourmalines are fibrous and surrounded by gray quartz.

Sempe mine

The pegmatite dike at the Sempe mine (Plate XVIII A) is very thick and shows the coarse upper part and the lower banded rock, in which, however, the bands are formed by small dark-blue tourmalines instead of by the more common garnets. The tourmalines show a very pronounced development of zonal color and are often in imperfect crystals. The lower side of the upper half of the pegmatite at the contact with the lower fine-grained rock, shows, where the latter has been removed, numerous cup-like depressions. They are fairly uniform in size, being about 1centimeter in diameter and several millimeters deep. These depressions were also noticed on one of the lower ledges on the opposite side of the hill. At this place the depressions in the same relative

position of the dike were larger being from 2 to 4 centimeters in diameter. The interior of these depressions is smooth, like the inside of a mortar. The middle part, with its coarse crystallization and pockets, is absent and the under surface of the solid rock apparently was pitted by corrosion. The Sempe mine has yielded pink beryl, lepidolite, and some tourmaline.

Hiriart mine

The Hiriart mine is in a pegmatite dike from 2 to 4 feet thick, which dips toward the west at an angle of about 30°. An open cut and a tunnel 75 feet long have not shown any evidence of the banded lower rock, the dike being fairly uniform in texture, (Pl. V B. p.   ) with abundant small flakes of biotite occurring at its edges. The rock surrounding the pegmatite is of a granitic character, and the dike may be either an independent one in a granite rock or a pegmatitic layer in the finer-grained bottom part of a much larger dike. Plates of muscovite, several inches across and showing a broad lepidolite border, have been found in the pay shoot. Embedded in the muscovite and lepidolite are small transparent tourmalines, many of which are of a deep-green color. Many of the green tourmalines occur in stellate groups in the lepidolite. The center of these groups is sometimes pink, as are also the centers of some of the green tourmalines. Nodules of montebrasite (amblygonite) are also reported, and a fine-grained lepidolite is said to occur in considerable quantity.

Prospects on Hiriart Hill

The claims named below have been slightly developed, and small quantities of lithium minerals have been found on almost all of them: the White Queen, Anita, El Moline, and Fargo. The pegmatite dikes on which these claims are situated are similar in character to those already described. It is highly probable that future work will show that the lithium minerals are widely distributed on this hill.

Bonsall

Axinite claim.

The axinite claim [in Moosa Canyon on T. A. Freeman claim– from Schaller notes] occurs in a granite area and at the open cut from which the axinite crystals were obtained the rock is so decomposed that its original character can not be determined. The axinite is found loose in the disintegrated rock and is associated with quartz, epidote, and laumontite. A large number of large crystals of axinite, few of which are of gem value, have been obtained. The crystals formed the basis of a crystallographical and chemical study of the mineral, the results of which have already been published.[41]

Tourmaline claim.

A few clear green tourmalines have been obtained from a small pegmatite dike in gabbro. The dike is 2 or 3 feet thick and lies nearly flat. A peculiarity of this pegmatite is

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[41] Schaller, W.T. Axinite from California: U.S. Geol. Survey Bulletin 490, pp. 37-47, 1911.

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the abundance of greenish feldspar. The quantity of tourmalines taken out is small, though the color is good and many of the crystals are clear. Small quantities of lepidolite, with associated opaque, pink tourmalines, have been obtained during the development work.

Rincon

The Rincon region lies between Pala and Mesa Grande. It has not been studied sufficiently to determine whether the gabbro occur at Pala extend through Rincon to Mesa Grande. At Rincon the gabbro is traversed by a multitude of pegmatite dikes usually only a few feet thick and having a parallel strike south and a westerly dip. The ledges are very numerous and generally show a division into two parts. The abundance of these small parallel ledges is illustrated in Plate III B. They consist of feldspar (orthoclase or microcline), quartz, and muscovite, and in less quantity of tourmaline, beryl, garnets, and some other minerals. The feldspar is rather porphyritic, and shows in the rock as large white squares, several inches across. A feature that distinguishes the locality is the presence of beryl, both the common variety and also some good clear beryl of a bluish-green color, pale aquamarines. Golden beryl is reported to have been found here recently.

Two mines have been developed near Rincon, one, the Victor, being essentially a beryl mine, and the other, the Mack Mine, being a producer of various lithium minerals, such as spodumene, tourmaline, and lepidolite.

Victor Mine.

The Victor mine is located on a pegmatite dike dipping westward and having a thickness of about 5 feet. An open cut about 50 feet long disclosed in the middle of the ledge, where the texture of the rock is coarsest, numerous pockets in which crystals of beryl, quartz, and feldspar are abundant.

The beryls are either opaque, blue to blue-green and yellow-green, or they are transparent gem crystals of a pale-blue color. The crystals show some variation in crystal habit. Ordinary beryl is six-sided with the flat base; a peculiar greenish soapy-looking variety occurs with an acute termination; and the gem crystals have a rounded appearance, due to the presence of many forms in the prism zone, and are terminated by the base and by other forms very slightly developed.

Mack Mine

The Mack mine is a short distance south of the Victor, and the open cut developments have revealed a large pegmatite dike nearly 12 feet thick and carrying numerous pockets, in which are found the usual gem minerals of the region-spodumene, tourmaline, pink beryl, and the associated minerals. A brief description of the minerals found here has been given by Rogers. Spinel is unique for this locality, and of the rarer minerals metallic bismuth and various zeolites may be mentioned.

Mesa Grande

The mines at Mesa Grande are several miles west of Warner's Ranch and just below the southern end of Smith's Mountain. The strip of mica schist that (according to Fairbanks) runs through the county in a northwest direction, passes a short distance to

the northeast. While very undulating in detail, the entire region is a large and high plateau about 4,000 feet above sea level, the highest elevation being 4,478 feet. The elevation of the mines is about 4,000 feet. The rock of the mesa is granite, and gabbro of which an extensive body, several miles across, has been traced for a length of 6 miles in an easterly direction. In this gabbro are the pegmatite dikes on which the mines are situated. Besides those pegmatites in which gem tourmalines are found, there are a number of others, which, so far as known, are free from lithium minerals.

The general relation, geographically and geologically, of Mesa Grande to the rest of the tourmaline field can be seen by reference to figure 2 on page   .   A   very general sketch of the geology of the region around the Mesa Grande mines is shown in figure 25.

Figure 25. Geology of the Mesa Grande region.

There are three important mines located here, of which two have produced tourmaline continuously for the last 10 years, and have been largely instrumental in attracting attention to the wonderful tourmaline deposits in San Diego County. The two mines adjoin and are the San Diego and the Himalaya. The Esmeralda, lying farther west, has also produced much gem material of value. There are several other neighboring mines in which small quantities of gem mineral have been found.

Like the Pala region, the gabbro mass contains numerous pegmatite dikes, in some of which the gem tourmalines and associated minerals have been found. These dikes are fairly numerous but they do not outcrop in such profusion as at Pala, and they are, moreover, much thinner. In consequence of late years all the work at Mesa Grande has been underground mining. At one of the mines there are over half a mile of tunnels and stopes.

San Diego Mine.

The first prospecting work done on the San Diego mine was in the nature of small open cuts on a pegmatite dike. These revealed the presence of gem tourmalines, and it was decided to follow the dike underground. A tunnel was dug into the hill some distance below the outcropping dike and at right angles to its strike. When the dike was struck, it was followed by a tunnel and was then traced up to the surface at several points to give air-shafts for ventilation. A portion of the dike was then stoped out, columns being left to support the hanging wall.

The pegmatites dikes are about 2 to 3 feet thick, and strike north 45° west, dipping south 45° west at an angle of about 30°. One of these pegmatites, on the property of the San Diego Tourmaline Mining Co., shows beautifully the division of the entire ledge into a coarse upper part and a lower finer-grained banded rock, with the middle part containing the pay shoot, between. Other dikes show no indication of the lower finer-grained banded rock, but consist entirely of the coarse pegmatite.

The developments of the San Diego mine have shown the presence of three distinct dikes, whose relative position are shown in figure 26. Several small stringers are also present, generally not far from a larger dike. A plan of the mine workings (up to 1909) is shown in figure 27 which is compiled from a map by Mr. Arthur Watkins, for many years the superintendent of the mine, and a copy of which was very kindly furnished by the Naylor Gem Co., the present owner of the mine.

Figure 26. Relative positions of three pegmatite ledges, San Diego mine, Mesa Grande.

Figure 27 Plan of mine workings, San Diego mine, Mesa Grande. The surface workings are shown in dashed lines and the underground tunnels and stopes are drawn in full. The three dikes are also shown and a fuller description of them is given later.

The surface workings consist of small open cuts, the northernmost of which, near the Himalaya mine, is on the same dike as that mine. Some of the pegmatite lying on the dump shows a fair quantity of lepidolite, usually in coarse scales and often of a rich purple color. With it are associated large red and yellowish-green tourmalines, mostly of no gem value, as they are much flawed. Muscovite having a lepidolite border is frequent. The longest open cut extends for about 100 feet along the pegmatite part of which has been removed for several feet below the original surface. The entire cut shows the lower banded rock and also exhibits its varying character. Some good tourmalines have been obtained from that part of the ledge which was removed. It is said that a small pocket of deep blue crystals was found about the middle of the cut. In the adjoining cut the dike shows very well the upper and lower parts. In the southernmost cut lepidolite is abundant, and numerous specimens of muscovite having a lepidolite border could be found. Some little distance south are a number of open cuts but no work has been done on them for some time.

The underground workings are more extensive. The older workings consist essentially of the upper tunnel, following the strike of the dike, and three air shafts, besides the tunnel by which the mine is entered. A long tunnel at right angles to the strike of the dike has been dug south of the present working and has struck pegmatite, probably the dike on which the older workings were located. An air shaft has followed the dike to the surface about 15 feet away from the tunnel. At the extreme northern end of the upper tunnel a stope follows a small dike to the surface. This dike, No. 1 on figure 26 and 27, is the same one on which the adjoining Himalaya mine is located. At the San Diego mine, this dike has a thickness of 22 inches and a dip of 30°$, 45"W. A seam of clay 1inch thick is on both sides, and an air shaft follows the dike to the surface where the northern part of this mine ends. About half way up to air shaft, a stringer leaves the main dike (fig. 28) and soon continues in a parallel position, but a short distance above it, as is shown in figure 26. The derivation of this stringer from a larger dike suggests that the numerous dikes on Hiriart Hill, at Pala, may be connected with the large dominant San Pedro dike in a similar way.

Figure 28 Pegmatite dike with stringer, San Diego mine, Mesa Grande.

Four and a half feet below the main dike is a small parallel dike. The part exposed in the tunnel varies in thickness, being 7 inches through at top and bottom and only 2 inches thick in the middle. A short distance north of the entrance from the main tunnel, a dike outcrops from the floor and at the tunnel reaches a height of 6 feet. This is referred to as dike No. 2 on figures 24 and 25. It has a thickness of several feet, but over the southeast corner of the tunnel in thins abruptly to 5 inches and then becomes wider again. This is shown on Plate   . Farther on the dike swells out to its maximum thickness of 6 feet. At an intervening place it divides into four distinct parts of unequal thickness, inclosing the gabbro between them. (Pl. XIX B). The dike is irregular in both strike and dip. The gabbro in contact with the dike often shows what looks like slickensided surfaces. The contact line of the edge of the dike is extremely sharp. Everywhere a knife edge might be placed at the line along which the pegmatite and the altered gabbro are in contact.

The long tunnel south of these workings has a length of 260 feet. Thirty feet from

the end, a dike about 2 feet thick was struck, but it varied and dipped about 30°S 45° W. At the end of the long tunnel is a small pegmatite stringer 2 inches thick and dipping 40°S. 40°-50° W. The dike above mentioned is either No. 2 or No. 3 as shown on figure 16, though the existence of the small 2-inch stringer would seem to indicate that the ledge was No. 2, the stringer being the same one as mentioned, occurring in the northern part of the mine. a few feet below ledge no. 1. What is apparently this same stringer will again be mentioned in the description of the Himalaya Mine.

The mine workings developed sine 1904 were so closely timbered in 1909 that the character of the pegmatite or the mode of occurrence of the gem tourmalines could not be noted. Nothing indicated, however, that there were any special differences from those of the older workings.

Tourmaline is the only gem mineral obtained. It occurs in black crystals, also in red, pink, blue (not abundant), green (of various shades, mostly yellowish-green), yellow, and colorless crystals. Many of the crystals are terminated, doubly terminated ones being common. The crystals are also frequently multicolored, pink crystals with green tops being the most characteristic.

Himalaya Mine.

Adjoining the San Diego mine on the north, lies a group of claims which in their entirety are known as the Himalaya mine. This mine has produced more and finer tourmalines than any other in the entire field, and in some parts of it the gem tourmalines were so abundant and of such perfection and beauty as to cause considerable wonder and excitement. The main workings have all been on a single pegmatite ledge (No.1of the San Diego mine) and up to 1904 consisted of open cuts (fig. 24). Since then, however, another ledge has been followed underground where extensive developments have resulted. The first tourmalines found at Mesa Grande were obtained from this property, being picked up in the loose dirt resulting from the disintegration of the pegmatite. It is said that the place was long known to the Indians and to the few white people living in the vicinity, but none knew of its value. Some specimens finally found their way to the Eastern States and were recognized as tourmalines, and the property was rapidly developed to its present stage.

The pegmatite dike of the Himalaya mine belongs to the symmetrical type, with a similar upper and lower part. A small layer of banded rock, a few inches thick, occurs at both the top and the bottom of the dike, the rest of the dike being a coarse granular aggregate of feldspar and quartz with more or less graphic granite. The extreme bottom, and likewise the top, is usually stained black, probably from manganese oxide derived from decomposing garnets.

The one dike from which most of the tourmalines have been obtained has been followed for over 1,000 feet and outcrops on the east side near the summit of the hill for about 700 feet, of which 500 feet is worked by open cuts (fig.   ).

The open cuts follow the strike of the ledge, and have cross cuts at right angles by which the waste material is carried away. The dike at the southernmost cut is 27 inches thick and dips S.30°- 350W. A short distance north the ledge is 22 inches thick. At a larger cut, 80 feet long, the dike is 20 inches thick and dips 35°-40°S. 45°W. The banded rock at the bottom goes up for 6 inches. In this cut can be well seen a fault with a throw of about 2 feet (Plate XXII A). The fault cannot be traced in the surrounding altered gabbro, and probably took place while the gabbro was yet firm and fresh. Lepidolite occurs abundantly in this open cut, usually as coarse scaly masses of a deep red-purple color; it is also frequent as a border on muscovite. Pink tourmalines are also abundant, and it is stated that a large quantity of gem material has been taken out of

this cut. Farther north is a small cut 25 feet long where the dike has a thickness of only 19 inches and dips S.40°W. A distance of 200 feet of pegmatite had not been touched.

Figure 29 Plan of mine workings, Himalaya Mine, Mesa Grande.

At the north end of the 200-foot undeveloped strip of land, is the main open cut, a general view of which is shown in Plate XX B. The entire cut has a length of 220 feet and follows the strike of the dike, which was covered with dirt when the photograph was taken. At places the dike has been followed below the surface for many feet and entirely removed. At the south end of the cut the dike has a thickness of 24 inches. A large quantity of fine gem tourmalines has been obtained here, one pocket having produced magnificent specimens of deep blue tourmalines grown in and on clear quartz crystals. At the north end of the cut, the dip of the dike, here about a foot thick, is well shown by the few remnants still left. A view of this part of the cut is shown in Plate XX B. Most of the dike has been entirely removed. The photograph also shows the tendency of the dike to creep or sag near the surface. A 5-foot wall has been left, on the other side of which there is another small cut about 40 feet long and the last open cut on the southern side of the hill. A small stringer of pegmatite, 4 feet below the dike, is here well exposed. The cut exposing it is about 10 feet wide. On one side the stringer dips about 30° and is 4 inches thick; on the opposite side, the dip is 40°-45° and the thickness only 1inch. It is believed that this is the same stringer as that found in the northern part of the upper tunnel of the San Diego mine and also encountered near the end of the long tunnel at the southern end of the San Diego mine. If this is so, there is here represented a narrow stringer with a length of xyz feet and a maximum thickness nowhere of more than 7 inches and a minimum thickness of 1inch.

Beyond this point, a different pegmatite dike forms more or less of a blanket on the western slope, as is shown in Plate XXI B. For a distance of 150 to 200 feet the dike has not been worked, but below this for 350 feet, almost the entire pegmatite has been broken up in mining for tourmalines. Another dike, a short distance below the main one, has been opened and worked for its gem stones. This is probably dike No. 2 of the San Diego mine. This dike has a thickness of 22 inches and dips S.35°W, This dike can be traced for about 300 feet with a strike of N.70°W.

A tunnel 200 feet long was dug into the eastern side of the hill with the intention of striking the pegmatite dike underground. At its extreme end a small stringer of pegmatite 1inch wide and dipping 30°SW was found. Several small cuts also have been dug on the lower dike on the eastern side, but no great amount of work has been done at that place.

The underground workings have been developed since 1904, but they are no complete description of the dike can now be given. 'Where the pegmatite could be examined it was seen to have the same general character throughout. There were places where the dike was solid rock without any pay shoot for many feet and then an area might be encountered where the pay shoot became rather large and formed a considerable part of the entire dike. In these cases, gem tourmalines were generally very abundant.

Gem tourmalines occur in this mine in greater abundance and of better and more varied character than in any of the other mines in southern California. The prevailing color is pink, but almost all colors and possible shades are well represented. The crystals are frequently multi-colored, the gradation being exceedingly delicate. Many of the crystals reach a very large size for lithia tourmalines, but these largest ones are mostly flawed. Many have a diameter of 2 inches and are 5 inches long. The best gem material is found in the smaller crystals, which are often clear, transparent, and

practically flawless. An immense number of such pencils of pink color and almost flawless has been found. Much of the pegmatite is in a fresh condition and in consequence many of the tourmaline crystals are "frozen", which is the term locally used to describe the occurrence of the crystals when they are firmly embedded in the solid rock. When such a crystal is found, if it is not desired to keep the specimen as such, the inclosing rock or mineral is broken with a sledge hammer till the tourmaline is loosened. In consequence of such rough treatment many of the fine crystals are shattered and broken into small pieces, with which the entire surface of the workings is fairly littered. Many fine crystals have also been lost or overlooked, and formerly an abundance of good clear tourmalines could be found in the loose dirt and on the dump.

When tourmalines are obtained they are collected in sacks and afterwards washed and cleaned.

Esmeralda Mine.

At the Esmeralda mine there seem to be several pegmatite masses, though the main workings are on one large pegmatite body. The dikes are very much broken, and it is difficult to say whether the several pegmatite outcroppings represent parts of one dike or several dikes. They vary from 10 to 15 feet in thickness. The structure of the dikes seems to differ from that usually found at Mesa Grande, though the workings have not been sufficiently developed to show the structure clearly. The upper and lower parts seem to be a coarse biotite granite with the coarse pegmatite in between. The coarse pegmatite in which are found the lithium minerals consists of quartz, feldspar, tourmaline, a little mica, and also graphic granite, which occurs abundantly. The apparent differences in structure may be due to the fact that the dikes are much broken and displaced and parts of the original dike have probably disappeared from place. In this mine have been found several pockets with very large quartz crystals, one of which is stated to weigh 148 pounds and to contain seven pink beryls embedded in it.

Prospects at Mesa Grande.

The Mesa Grande Consolidated Co. has prospected by several inclines with drifts and stapes a pegmatite ledge a little south of the Himalaya mine. The pegmatite ledge is said to vary in thickness from 6 inches to 3 or 4 feet and to have a northwest strike and a southwest dip. Pink tourmaline suitable for cutting has been obtained.

At the Trail mine, on the same ridge as the Esmeralda and just above it, dark-blue tourmaline and pink beryl are reported.

The Cota mine is a short distance southwest of the Himalaya and is developed in a flat lying pegmatite from 2 to 5 feet thick. Variously colored tourmalines and garnets have been obtained from the pockets.

` About 4 miles northwest of Mesa Grande is a large pegmatite exposure 35 feet wide in which occur segregations of large pure masses of both feldspar and quartz. Rose quartz and some garnets have been extracted.

Ramona

General features.

The mines near Ramona are near the stage station on the road from Ramona to Julian and about 4 miles east of Ramona. There are several mines from which gem

minerals have been taken. The most important are the Little Three and the Surprising mines. Lepidolite is said to occur in all the mines; pink beryl containing some lithium is found; and dark green tourmalines are abundant in several of the mines. A view of the country showing the pegmatite dikes, which are in gabbro (earlier described p.   ), is shown in Plate XXIV A

Little Three Mine

At the Little Three Mine the pegmatite dike strikes about N.70°W. and dips southwest at a low angle (about 25°). The upper part of the dike is coarse graphic granite containing large black tourmalines and is about 3 feet thick; the lower part is the fine-grained banded rock, also about 3 feet thick. Small blue-black tourmalines instead of garnets, form the wavy bands and give the rock more of a blue color than is found elsewhere. Between the upper and the lower parts is the pay shoot containing many large pockets in which are found topaz with albite, tourmaline (green), orthoclase, lepidolite and quartz, all remarkable for their large size. Plates XXII B and XXIII A give views showing the character of the pegmatite in this mine.

A thin section of the upper graphic granite shows the rock to consist of microcline, albite, and quartz. The albite seems to be present in greater quantity than is usual for graphic granite. The lower banded rock shows abundant tourmalines instead of garnets, a few of which are, however, always present. The other minerals are quartz, albite, orthoclase, muscovite, and microcline in small rectangular areas.

The pay shoot contains many large pockets from which have been obtained large green tourmaline, also topaz, albite, lepidolite, and quartz, all in crystals. One pocket was 10 feet long and from 6 to 18 inches wide; another pocket about 2 feet wide but very irregular in shape was traced for nearly 30 feet. The topaz crystals are often perched on the white, tabular albites and are also found on the tourmalines. The crystals are often an inch through and show good faces, being etched very little. They have a wedge shape due to the dominance of a brachydome face, and almost all have exactly the same crustal habit. They are different in appearance from the topazes found at the Surprise mine and resemble closely the Russian topazes. Tourmaline occurs in large crystals 5 inches thick, of a greenish- black color, often ·with a transparent green top. They are almost always terminated by the basal plane. The black tourmalines are often entirely changed to muscovite. Lepidolite occurs rarely in scaly pale- pink masses and is abundant as sharp crystals 2 inches across. This is the first occurrence of perfect crystals of lepidolite which are described in detail on pp. to . The individual crystals are grouped together, forming large masses a foot thick. Albite occurs in beautiful masses of tabular crystals, which have sharply outlined crystal faces and are often of large size. Quartz occurs frequently in large smoky crystals. Small crystals of columbite have also been found. The mine is noteworthy as being the second locality in California where stibiotantalite has been found.

Surprise Mine.

On the same dike, but some distance away, is the Surprise mine, in which two separate open cuts have been developed. Garnet is the only gem mineral obtained in the western cut; topaz, beryl, and green tourmaline are found in the second or eastern cut. The latter cut is shown in Plate XXIII B, which shows the line of pockets in the middle of the dike. The garnets occur in the hard pegmatite and are also found in the loose dirt filling the pockets of the pay shoot. They are usually small and rather flawed, but occasionally some large clear pieces are found which cut into brilliant stones of a

fine reddish-yellow color. The topazes are found loose in the dirt in the pockets. They are of two kinds, small colorless stones! usually less than a centimeter in length, and larger pale-blue stones. The colorless stones usually show crystal faces, though none of the edges (except in the prism zone) are sharp, the entire top of the crystals having been much subjected to etching. Several kinds of beryl have been found here, namely, pink (similar to those found at Oak Grove), white, and two remarkable, colorless, and perfectly transparent crystals. These two crystals are remarkably etched and eaten away. A description of them is given on p.

Prospects at Tamma.

The A. B. C. claim, also known as the Daggett mine, has been developed by two open cuts and by a short tunnel about 20 feet long with a 45 foot stope following the dike. The pegmatite dike, about 7 feet thick, strikes north and dips westward at an angle of about 35°. In the pockets of the pay shoot were found pink beryls and large greenish tourmalines. Garnets associated with black tourmalines were also noted in places, and lepidolite is reported as having been found.

The Hercules claim is on the hillside above the Little Three, and a 90-foot tunnel has followed a dike 4 feet thick, which strikes N.70°W. and dips southwest at an angle of about 45°. Fine garnet crystals have been obtained here, and also beryl, greenish tourmaline, and many smoky quartz crystals.

The Lookout claim lies northeast of the Hercules and the dike strikes N.65°-70°W. and dips southwest at an angle of 50 °. Some garnet and greenish tourmaline have been found.

The Reliance claim, west of the Little Three, embraces two dikes 10 feet apart. The dikes parallel the other dikes of the region and are 2-1/2 and 6 feet thick, respectively. Some beryl, lepidolite, and greenish tourmaline have been obtained.

The Mars and the Prospect claims have also yielded garnets of gem value.

Banner

It is reported that a prospect near Banner has been developed by a short tunnel and that the pegmatite showed the presence in it of considerable lepidolite.

Oak Grove

Oak Grove is situated on the eastern side of the lofty mountain mass locally called Smith's Mountain and also known as Palomar Mountain. The southeastern spur appears as Palomar Mountain on the topographic maps of the Geological Survey, and the use of the name by the writer is understood to refer to that spur, the entire range being called Smith's Mountain. Oak Grove lies between Coahuila and Mesa Grande.

Smith's Mountain is a wild and rugged range having a north and south trend and reaching a height of 6,500 feet above sea level. It is said to consist almost entirely of "granite" and mica schist, though in Palomar Mountain is a large body of gabbro with granitic pegmatites. The "granite" varies considerably and detailed study of it will probably show that the rock now called "granite" is reality consists of a number of different rocks.

On the trail from Oak Grove to the mines, several small areas of gabbro rocks are passed, and after the main mass of gabbro is entered numerous small pegmatite dikes are crossed. On one dike that is at least 10 feet thick and dips westerly at a high

angle three claims are located from which lithium minerals have been obtained. The three claims are owned by Mr. Bert Simmons, Mr. K.C. Naylor, and Mr. W. Dyche and others, and the names of their owners are given for reference.

Simmons Mine.

On the Simmons claim, also called Gem No. 2, several open cuts have been dug, one of them going down; it is reported, 14 feet without leaving the pegmatite. The principal mineral of value obtained here is tourmaline, but, in addition, lepidolite, albite, and pink beryl, and also orthoclase, quartz, muscovite, and garnet are found here. The tourmalines are small and occur mostly embedded in a reddish clay, which forms irregular streaks near the center of the pegmatite ledge. This clay is called "gem clay." Besides the tourmalines, quartz and mica are often embedded in it. The color of the tourmalines varies from colorless to pink, blue, and green. They are all pale; but sometimes the crystals are good and clear, and they are very brilliant when cut into small stones. The colors most frequent are pale pink and pale green. The largest crystal seen from this locality was pale green, fairly clear, and about half as large as the little finger. The lepidolite occurs sparingly in small lilac scales intimately a5sociated with white albite crystals. Several pink beryls have also been obtained here. The largest one measures 110 by 75 by 65 mm and weighs 850 grams; it is transparent, though more or less cracked, and has a pure pink color. It is further described on p.

Naylor Mine.

Adjoining the Simmons mine is the claim known as the Naylor mine. Three small open cuts and one short tunnel have been dug, but the main dike has apparently not yet been reached (1904), though the work has exposed several stringers containing lithium minerals. The tunnel has a length of about 20 feet and from the exposed stringers small gem tourmalines and lepidolite together ·with well- crystallized orthoclase, albite, quartz, and muscovite, have been obtained. The tourmalines are similar to those obtained from the Simmons mine. They are variously colored, pink, green (pale), blue, yellow, and colorless. The stones are small and usually pale in color, though some of the cut stones are very brilliant.

Dyche Mine

The claim owned by W. Dyche and others lies on the same dike and southwest of the Naylor claim. The work done is represented by an open cut and several other smaller openings. The pegmatite is the normal orthoclase-quartz rock containing also muscovite, tourmaline (black), and albite, and in addition lepidolite and a few scales of green chlorite. Gem tourmalines are reported from the claim. The lepidolite seen by the Titer forms a border 1centimeter wide on muscovite plates, and is (relatively) fairly abundant. This border lepidolite is further described on p.

Riverside County

Coahuila

The term Coahuila is used to designate the rather indefinite region northeast of Oak Gove, and lies in southern Riverside County, southwest of the San Jacinto

Mountains. The region consists of a large valley with its surrounding mountains, the valley being separated by a small rise into two parts, the Coahuila Valley, on the west and the Terwilliger Valley on the east. The northwestern boundary of the valley is Coahuila Mountain, a bold mountain, attaining an altitude of 5,635 feet and visible for a long distance. The mountain is a favorable place for prospecting, and a number of claims are laid out on it. On the northern spur is situated the Fano mine, on the northwestern side the White Cap mine, and on the southern and southwestern sides are many claims, from which some common beryl of no gem value has been obtained. The eastern side of the valley is bounded by a range of mountains known as Thomas Mountain, and on the summit of the southern spur is situated the oldest gem-tourmaline mine in southern California.

The map (figure 30) shows the general geological formations of the region. The core of Coahuila Mountain consists of a nearly square mass of orthoclase-quartz granite with but little mica, surrounded on all sides by gneiss or mica schist. The white core is a very prominent feature and is noticeable at a distance, the surrounding gneiss being rather dark colored and dipping away from the center on all sides.

Figure 30 Map of Coahuila region.

On the southwestern side of the mountain is an area of gabbro in which are at least six, and possibly more, pegmatite dikes that dip westward at a fairly high angle. The dikes average about 5 feet in thickness, and consist of feldspar and quartz, with subordinate quantities of muscovite and black tourmalines. Several claims are located here, though no work has been done and no gem or lithium minerals have, as yet, been found. On the northwest corner of the orthoclase-quartz granite is a small body of metamorphosed limestone. The rock is thoroughly crystalline, and the rhombic cleavage of the calcite has been well developed. Epidote and garnet have been found in it as products of metamorphic action.

White Cap Claim.

North of the limestone lies a small body of gabbro in which is a pegmatite dike a few feet thick. A claim on this dike is known as the White Cap, as the pegmatite forms a white cap on the summit of the small hill composed of nearly black gabbro. Two small open cuts have been developed and these have yielded tourmaline, lepidolite, albite, and pink beryl. The tourmaline occurs in small pink crystals in the lepidolite, which has a lilac-pink color and is in scales several millimeters across. The albite forms tabular crystals and is associated with the lepidolite. Although but little work has been done, the occurrence looks very promising.

Fano Mine.

On the northeastern side of Coahuila Mountain is an extensive body of gabbro, which extends for many miles toward San Jacinto. This gabbro contains several pegmatite dikes on which claims have been located. West of this gabbro lies a large mass of granite composed of orthoclase, quartz, muscovite, and biotite. In this granite are several pegmatite dikes, which comprise constitute the Fano Mine.

On a dike in the granite a small l open cut has been developed, and spodumene is reported to have been found in the loose dirt; some blue tourmalines and lepidolite are also reported. A long tunnel has been driven into the granite below the open cut. This tunnel struck the dike ·within a few feet and passed beyond it into the granite for

some distance. An examination of the dike revealed no indications of the presence of any lithium minerals. The spodumene reported from here is mostly colorless and more or less opaque-similar to the float spodumene at Pala. A few small pink pieces have been reported as coming from here. Common beryl is abundant and occurs in large crystals and also as small groups of minute crystals. The beryls are similar to those found on the south side of the mountain.

Thomas Mountain Mine.

Thomas Mountain forms the northeastern wall of Terwilliger Valley, and is one of the westernmost spurs of the San Jacinto Mountain Range. The mountain consists of granite and gneiss, including also, on the summit of its southern end, a small body of gabbro. This gabbro encloses a pegmatite dike in which is the mine from which gem tourmalines were first obtained in California about 40 years ago. This mine is also known as the Columbia.

The pegmatite dike is a few feet thick and dips westward at a low angle. It consists of feldspar and quartz, with smaller quantities of muscovite and black tourmaline. An open cut and a short tunnel are the results of the work done. The mine has lain idle for many years. The tourmalines, the only lithium minerals found, are large and are usually pink and green. They are not clear and flawless, but the crystals have been cut across and polished, making very handsome specimens. The crystals found in museums as coming from this mine are usually merely labeled "San Jacinto Mountains". Nothing is known as to their mode of occurrence. Not a trace of lepidolite was seen in the ledge or on the dump.

Anita Mine.

The Anita mine lies west of Red Mountain, about 6 miles northwest of the summit of Coahuila Mountain. The country rock around the mine is granite. The pegmatite dike varying from 5 to 20 or more feet in thickness pitches northwest at a fairly steep angle. The dike is uniform in its rock character and consists of graphic granite; it has a well-defined central pay shoot composed of coarser quartz, feldspar, tourmaline, and other associated minerals; and its lower half is finer grained in texture than the upper part. The extreme edges of the pegmatite carry some biotite and are finer grained and more compact than the remainder of the dike. In the central pay shoot are often found masses of quartz, albite, and blackish-green tourmaline. Massive quartz usually surrounds the pockets in the pay shoot. The large black tourmalines above the pay shoot often reach down into a pocket, changing from green or blue colors to finally a pink, and then often becoming more or less transparent. Some very large tourmalines have been found here having a good variety of colors in the transparent crystals. Some of the colors are more intense than usual, and in addition to a deep-brown shade, some emerald- green and deep ruby-red colors have been obtained. Some of these stones are identical in color and shade with the red Arizona garnets (Arizona rubies).

The mine has been extensively developed, and the accompanying map, copied from one kindly furnished by Mr. A. E. Dougherty, gives an idea of the mine workings and of the distribution of pockets in the pay shoot.

Figure 31 Plan of the Anita mine, Riverside County.

Other occurrences of lithium-bearing pegmatites in the United

States

South Dakota

Black Hills

The geological relations obtaining in the Black Hills of South Dakota have been well summarized by V. Ziegler.[42] According to him the Black Hills consist of a series of uplifted sedimentary formations dipping away radially from a central core of pre-Cambrian metamorphic and igneous rocks. The sedimentary formations are of the Paleozoic, Mesozoic, and Cenozoic ages. The pre-Cambrian rocks are a complex of slates, phyllites, graywackes, quartzites, and schists, cut by basic igneous rocks now metamorphosed into amphibolites. All are intruded by a much younger, but still pre-Cambrian, series of granites and pegmatites which center at Harney Peak. The granite of Harney Peak is coarse in texture and shows frequent and irregular gradations into pegmatitic varieties. The granites and the surrounding pre-Cambrian schists are cut by a great number of pegmatite dikes, which shown all gradations from a typical giant granite into well-defined quartz veins.

Of the many mines of this region wherein lithium minerals and their associates are exploited, the Etta mine near Keystone is the best known. The Etta mine, originally opened for mica, then further developed for tin, and now worked for spodumene, is situated on a small hill rising about 250 feet above the valleys on each side and having an altitude above sea level of about 4500 feet. The country rock is mica schist, in which are numerous outcrops of pegmatite remarkable for its coarseness. These pegmatite bodies have generally a round or elliptical outcrop. The surrounding schists have not been much altered, and the transition from schist to the pegmatite is abrupt.

The pegmatite forming the Etta mine measures about 150 by 200 feet. The outside rim for several feet consists of a rock much finer than the central core and free from lithium minerals. Biotite is rather common in places in this finer-grained rock. Inside of this rim is the coarse aggregate of minerals among which the spodumene is found, this being the only lithium mineral found in commercial quantity.

The spodumene occurs in large crystals scattered promiscuously throughout the coarse pegmatite. The crystals are usually several feet long but differ considerably in thickness. They vary from less than an inch to 40 feet in length, and some are 3-1/2 feet in thickness, contain 385 cubic feet, and weigh when not altered about 37 tons.[43] Though several crystals of these gigantic dimensions occur, the common length is from 2 to 10 feet. The spodumene is usually altered on the surface to a greenish, compact, clayey mass, which may form a layer several inches thick. This material is not suitable as an ore of lithia and is always removed and thrown on the dump. The spodumene rarely contains any inclusions of other minerals; a few pieces containing quartz have been noticed, and cassiterite occurs along joints. The cleavage is well developed in the crystals, which are easily broken into small pieces suitable for handling and joints make it impossible to remove large pieces without breaking.

The pegmatite rock is loosened by blasting and then broken down by the use of crowbars. The "logs", as these immense crystals of spodumene are called, are

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[42] Ziegler, V., The mineral resources of the Harney Peak pegmatites-1: Min. and Sci. Press, vol. 108, p. 604, April 11, 1914

[43] Schaller, W. T., Gigantic spodumene crystals, Mineralogic notes, series 3, U.S. Geol. Survey Bull. 610, p. 138, 1916.

uncovered and taken out in pieces not larger than a foot or so in diameter. The spodumene breaks easily, being very coarse grained and already somewhat shattered. The spodumene or lithium ore is segregated from the worthless feldspar and quartz and after the outer clayey shell has been scraped off the ore is loaded into wagons and transported to Keystone whence it is shipped by rail. It has been estimated that 20 tons of "dead rock", that is, rock worthless as lithium ore, has to be removed for every ton of spodumene obtained.

Figure 32. General features and mine workings of the Etta Mine, South Dakota.

Several other neighboring mines have produced spodumene and nodules of amblygonite occur at several places in shoots an pockets in the pegmatites. According to Ziegler[44] nodules weighing half a ton are common, and smaller nodules of so-called lithiophilite (more probably triphylite) occur disseminated through the pegmatite like the amblygonite but with more regularity in their occurrence and distribution. According to Ziegler the Black Hills, up to September, 1913, had produced lithia minerals valued at $143,000.

Production of lithia minerals from the Black Hills.
According to V. Ziegler.

Mineral.	Quantity (Short tons).	Value.
Spodumene	1400	30,000
Amblygonite	2800	110,000
Lithiophylite		
Triphylite	100	3,000

The pegmatites of the Black Hills have produced minerals at about $1,450,000 distributed as follows:[45] Mica, $1,167,800; lithia minerals, $143,000; tin and tungsten minerals, $100,000; miscellaneous $30,000.

New England Localities

The New England States in which lithium minerals have been found in any quantity, and have been mined for various purposes, are Maine, Massachusetts, and Connecticut. The Maine localities are still worked in a desultory fashion for their gems,

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[44] Ziegler, V. The mineral resources of the Harney Peak pegmatites-II: Min. and Sci. Press, vol. 108, p. 654, April18, 1914. See also Ziegler, V., Lithia deposits of the Black Hills: Eng. and Min. Jour., vol. 96, p. 1053, December 6, 1913.
[45] According to V. Ziegler, op. cit.

and the Haddam Neck, Connecticut, locality is now mined for feldspar whereas the other localities have not been worked, so far as I know, for several years.

The mode of occurrence of the lithium minerals is similar at the different places, occurring in pegmatite which is intruded into mica schist. All of the mines are small open cuts, the actual amount of work done being much less than that done in the California field.

Maine

A series[46] of albitic pegmatites[47] containing lithium minerals occur in the western part of Maine. These localities in the towns of Auburn, Hebron, Norway Peru, Paris and Rumford, are all within a narrow belt of about 40 miles in length. The total width of the belt, so far as has been observed, appears to be not much over 15 miles.

In general character the several localities are much alike, although in minor detail they vary considerably. Quartz, muscovite, albite, cassiterite, and amblygonite are always associated with the tourmaline and lepidolite, and other rarer minerals are often found. The general geological features of the Maine occurrences are shown on the map of figure 32, taken from Bastin's report.

Figure 33 Geological map of pegmatites in Maine.

Paris.

The famous locality known as Mount Mica, which lies about a mile eastward from the village of Paris, was discovered, in 1820, by Messrs. E.L. Hamlin and Ezekiel Holmes. Since that time large excavations have been made in the pegmatite in search of gem tourmalines, and the locality in one of those most noted among mineral collectors. It has been thoroughly described by various writers, especially by A.C. Hamlin[48] On account of the long continued explorations, the list of species found at Mount Mica is naturally much fuller than that for any of the other deposits.

The rock above the pegmatite ledge is mica-schist. In certain parts black tourmaline crystals become fairly abundant, which, at places, are arranged with their longer (vertical) axis perpendicular to the line of contact of the schist and pegmatite. In thin section the mica schist is seen to be composed mainly of biotite and quartz, and to contain also garnets and bands of andalusite or sillimanite in small crystals. The following description of the pegmatite is taken from Dr. Hamlin's book.

"As the work of opening up this locality progressed, the coarse granite (i.e., the pegmatite rock) of the upper layers of the ledge suddenly changed its character. The massive flakes and coarse crystals of albite, the large nodules of quartz, the broad plates of mica and the huge and numerous crystals of black tourmaline no longer appeared, and instead of them the ledge appeared to be composed of much smaller particles of the same minerals. The line of demarcation was quite apparent, yet there was no line of decided and distinct separation. Along this line of charged particles occurred the gem tourmaline deposits. They sometimes appeared in the granite (i.e. the pegmatite) a foot or two above this ill-defined line, but never below it. In all the cavities

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[46] Clarke, F.W., Researches on the Lithia Micas, Bull. U.S. Geol. Survey No. 42, 1887, pp. 11-27.
[47] New occurrences in Maine have recently been described by Bastin.
[48] Hamlin, A C., The History of Mount Mica, 1895

known not one was found below this change in the rock, which is made clear to the miner by the appearance of minute crystals of garnets, and to explore beneath has been thus far a waste of time and labor." The occurrence here is similar to that of California, the three parts of the pegmatite here mentioned being the upper, lower and pay-shoot of the California occurrences.

A small area of about 15 feet square, excavated in the early days, was fairly honey-combed with cavities which seemed to be somewhat connected with each other. There has been no connection with the pockets found at later periods, except in one or two instances where a small group of cavities occurred together. The appearance of lepidolite was often a sign of success, especially when followed by masses of smoky quartz, and when a broad layer of albite was found to be changing into regular and broken flakes, a deposit or cavity might be prophesied with great certainty to occur beneath. Many black tourmalines have been seen in the ledge or in the walls of the cavities, but ·with the exception of three minute crystals, not one has been found in the cavities among the fine crystals of the colored tourmaline.

The cavities generally were roofed with albite, while the sides were composed of limpid or smoky quartz mixed with lepidolite, crystals of cassiterite, spodumene, amblygonite, and other rare minerals. These cavities were of irregular shapes and of sizes extending from the capacity of a pint to that of four or five bushels, and their interior has generally been filled with a substance resembling sand, but which is disintegrated cookeite and lepidolite. Lying in this sand and generally at the bottom of the cavity appeared the beautiful tourmalines, often unattached and unconnected with any matrix. Sometimes they were attached to the walls of the cavity. Occasionally the quartz rock in the wall would contain fine crystals of pellucid or smoky hues, which were often transfixed with slender crystals of tourmaline of various colors. The walls of the cavities were often found rent and shattered. Sometimes the shafts of the perfectly crystallized tourmalines were found broken into two or three parts, and in other instances they were fractured into numberless minute fragments, falling into sand when touched by the hand.

From the data thus far obtained the area of the deposit is quite limited, and apparently does not extend over three hundred feet in length. Its depth is not yet determined, but at the depth of the deepest excavation- 16 feet-two of the largest and richest cavities were found.

Sometimes, the minute crystals may be seen penetrating limpid quartz. Well marked specimens of dislocated and curved crystals have frequently been found, and some beautifully radiated tourmalines of a transparent green color-never red-have been disclosed by cleaving masses of mica. Well defined crystals of tourmaline are found in the solid masses of quartz and feldspar whose sections have been separated at some distance by the intervening rock, as we often see in specimens of beryl.

Other localities

Hebron.-About seven miles southeast of Mount Mica is the well known locality of Hebron which, however, has been but little worked. All the exploration, so far, has been superficial; and yet many fine specimens of green and red tourmaline, cassiterite, amblygonite, cookeite, beryl, apatite, and childrenite have been obtained; muscovite, orthoclase, quartz, pollucite, herderite, arsenopyrite, and vesuvianite are also found. The lepidolite of this locality is of the ordinary, purple, coarsely granular kind; but it is especially interesting on account of the fact that it contains considerable quantities of the rare metals caesium and rubidium.

Norway.-This locality, which has been but little exploited, is about seven miles

from Mount Mica, in a southerly direction. With the lepidolite are associated, as usual, quartz, the feldspar, the micas, cassiterite, lithiophilite, beryl, &c., and also a peculiar rose red clay, derived from some other species by alteration. Most of the colored tourmaline is of a peculiar dark oily green tint, and the lepidolite is partly of a coarsely granular, white variety, and partly of a brownish, very finely granular sort.

Auburn.-The locality at Auburn is called Mount Apatite, which is about four miles north of west of the cities of Lewiston and Auburn. Up to 1884, all the work was carried on in a space 20 by 8 feet to a depth of 8 feet, when nearly 1500 crystals had been found. Since then the work has been much extended.

The mica-schist country rock is composed of biotite and quartz, the former in the characteristic shreds and the latter in allotriomorphic masses. A very little feldspar is also present.

The lithium minerals are found in pegmatite ledges which are intercalated with the mica- schist. There seem to be several of the ledges but a few feet apart. The pegmatite ledges dip north or a little northeast at a low angle. The line of contact between the pegmatite and the schist, though very sharp, is slightly wavy. A few inches below the upper line of contact of the ledge and the schist, a small lens of schist a foot long and an inch thick was seen in the pegmatite, the dip of the lens being apparently parallel to the dip of the ledge. A second small inclusion of schist, with a round cross-section, was also observed.

The pegmatite itself consists of feldspar and quartz with smaller quantities of muscovite; garnet and tourmaline (black) are also present; and large tabular masses of white albite are very common. The ledge may be divided into the following parts: an upper pegmatite about five feet thick, containing no gem nor lithium minerals;, consisting chiefly of orthoclase and quartz, often forming graphic granite and containing also biotite in small quantities at times seemingly altered to green chloride and also muscovite, black tourmaline and garnet. Then comes the "mineral sheet", a few feet thick, in which occur pockets lined by the minerals sought, which are also found loose in the bottom of the cavities; below this mineral sheet comes a layer of large garnets several inches through; and below this is a finer rock rich in garnets. Here also we have the three divisions noted at Paris and at California. The gem tourmalines from Auburn differ in appearance from the other Maine tourmalines, and are as a rule somewhat lighter in color. They are found colorless, light pink, light blue, bluish-pink, and light-green, and at times nearly all these colors are found in the same crystals. Some of the faintly colored crystals afforded gems that deepened very much in color after cutting. Lepidolite is found in some abundance in crystals or on crystals of quartz and feldspar, and also in globular masses of considerable size.[49]

The quartz occurs in crystals which are smoky in color and several inches long. These crystals and nearly all the crystallized quartz from this mine are capped or coated with a white, opaque coating, and the large quartz crystals are at times penetrated by the colored tourmalines. The albite, which resembles the cleavelandite of Chesterfield, Massachusetts, occurs here in abundance in plates piled together and forming irregular spaces. In these spaces and on the sides of the crystals are found implanted nearly all the minerals described. The lepidolite occurs in the ordinary purple, coarsely granular form, and also in remarkable perfection as a border upon muscovite. The other associated minerals are orthoclase, beryl, garnet, cassiterite, gummite (?), autunite, apatite, herderite, triplite, muscovite, leucopyrite, cookeite, troilite, amblygonite, and zircon.

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[49] Clarke and others. Contributions to Mineralogy. Bull. U. S. Geol. Survey No. 262, 1905. p.

Rumford.- The Rumford locality was discovered many years ago by Mr. E.M. Bailey, of Andover, Maine, but it was not opened unti11883, since when it has been worked for its mica (muscovite).

The lithium minerals occur in a large mass of pegmatite which is very irregular in shape. The country rock is essentially a mica-schist, though it varies somewhat in its composition. The common phase of the rock is composed essentially of biotite and quartz, with apatite and possibly also andalusite. A rarer phase has more the character of mica diorite, but its field relations in regard to the ordinary mica-schist were not made out. Lepidolite, tourmaline and spodumene are the chief lithium minerals found in the pegmatite.

The larger portion of the lilac lepidolite is coarse in structure, and contains many small, opaque, red tourmalines. The color of the latter is very rich, and some are found in radiated masses of considerable size; but so far no true gem material has been obtained at the locality. The appearance of the associated lepidolite and tourmalines is strikingly characteristic and resembles nothing from the other localities of the region. Green tourmalines are found sparingly, and so also are amblygonite and cassiterite. Spodumene, however, is one of the notable features of the deposit, occurring in masses of great value. Faces of this mineral over three feet in length can be observed at several points along the ledge. At the other lithium localities in Maine, spodumene is comparatively scarce.

A second deposit of lithium minerals near Rumford has recently been opened.[50] The exposed ledge is five feet thick and has been traced for three hundred feet. Pockets containing gem crystals have been opened and the color improves with depth. The principal color is light green, but colorless, pink, and blue tourmalines are also present as well as the associated minerals quartz, feldspar, muscovite, lepidolite, amblygonite, opaque and pale lilac spodumene.

Peru.-This locality is of special interest as affording the rare minerals petalite. Associated with it, the following minerals have been reported; pyrite, columbite, spodumene, triphylite, chrysoberyl, and amblygonite. Probably also quartz, orthoclase, muscovite, tourmaline, and lepidolite are present.

Winslow.-According to Mr. W.P. Blake[51], lepidolite occurs at Winslow, Maine, associated with cassiterite. The vein of tin ore is in mica schist, and the filling of the vein consists of white mica or lepidolite on each wall, then a medial line or mass of fluorspar, in which the crystals of cassiterite are irregularly dispersed.

Massachusetts

The principal lithia localities in Massachusetts are those in the neighborhood of Chesterfield and Goshen in the western part of the State. These have been described by Mr. AA. Julien,[52] and the geology has been briefly discussed by Prof. B.K Emerson.[53] The following notes are taken entirely from these two papers, chiefly

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[50] Webb, H.G., A remarkable tourmaline deposit. The Mineral Collector, XI, No.8, p. 126, Oct. 1904.

[51] Mineral Resources of the United States, U. S. Geol. Survey, 1882.

[52] Julien, A.A., On spodumene and its relations, from the granite veins of Hampshire County, Mass.; Annals of the N.Y. Academy of Sciences, vol. I, 1879, pp. 318-354.

[53] Emerson, B. K., Geology of Old Hampshire County, Mass.; Monograph. U. S. Geol. Survey, vol. 29, 1898.

from the first-named, as the place was not visited by me.

Spodumene occurs at numerous localities in Hampshire County in crystals of remarkable size and perfection. Here it is found in coarse granite veins, huge lenticular masses of that rock, having sometimes great extension but little thickness and enclosed between the highly-titled beds of the stratum of staurolitic mica-schist, succeeding each other at intervals of several miles along the strike. These granite veins or pegmatite dikes occur on the periphery of the nearby great granite area and are not found within this granite area.

The more easterly of the Goshen veins consist mainly of a coarse aggregate of albite, blue tourmaline, garnet, and spodumene. The Barrus vein to the west consists of a coarse aggregation of white quartz, orthoclase, muscovite, and occasionally greenish beryl, while the scattered bowlders of albitic granite appear to be fragments of a central band or secondary vein. In these are found spodumene, tourmaline (black, green, or blue-black (indicolite), generally massive, but sometimes in good crystals), beryl (green, and white (goshenite), in grains, or sometimes fairly crystallized with good terminations) garnet, rose-colored muscovite, and still more rarely columbite and cassiterite in minute crystals.

At Chesterfield, the schists have been worn away from the main pegmatite which stands up in a vertical wall 33 feet high. In many places a veneering of schist remains attached, and when it is removed the impression of the schist is sharp and clear on the surface of the pegmatite. The layer of schist against which the pegmatite rests shows no sign of its influence, thus differing from the schists in contact with the albitic granite at the Barrus farm, where the contact metamorphism is pronounced and the granite and schist are fused together. A secondary vein is seen high up on the face of the vertical side of the main ledge, and seems to have been deposited in a vertical transverse fissure in the latter, which fissure extends from the east face only about halfway across the ledge and to an intermediate distance up and down.[54]

At this locality, altered spodumene or cymatolite is abundant. The more slender of the pseudomorphous crystals are often found penetrating the coarse masses of beryl, but the latter is never enclosed.

At several other places, notably Chesterfield Hollow and Huntington, similar occurrences of pegmatite were noted and described.

The geological relations of the area described is shown in figure 34.

Figure 34 Geological map of pegmatites in Massachusetts. After Emerson.

Connecticut.

Haddam Neck.

The fine gem-tourmalines of Haddam Neck[55], Connecticut, are obtained from a feldspar quarry at that point, situated a few rods from the east bank of the Connecticut River. The feldspar is part of a large pegmatite mass which is in mica schist. There are two points where openings have been made. The main quarry is an excavation about 95 feet in length and 50 feet in width, and has been carried down some 40 feet in snow-white feldspar; the other lies a hundred yards to the southwest, and here the pegmatite shows an outcrop of perhaps 130 feet in length, and 26 feet in width. At the main quarry the excavation has followed down the west side of the ledge, but though extended

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[54] Emerson, loc. cit.

[55] Known in 2022 as the Gillette pegmatite.

eastward for 50 feet, the opposite wall has not yet been reached.[56]

At the quarry from which the lithium minerals were obtained, the pegmatite rock is in mica- schist, which is seen in thin section to be composed essentially of biotite and quartz With magnetite and apatite, and a very few plagioclase feldspars. The field relations seem to show that the pegmatite was intruded into the mica-schist. The contact line is irregular and often wavy. A deep soil hides the formation except where quarrying has exposed the fresh rock, so that the relations of a body of gneiss, occurring some hundred feet away, to the schist are not discernible.

The gem tourmalines occur principally near the eastern border of the ledge, in a zone two or three feet wide, where the feldspar is largely intermingled with other minerals, chiefly quartz, muscovite and lepidolite, garnets, black tourmalines, and several other species of less value. The colored tourmalines are chiefly green, but many are pink, and even red (rubellite), and various tints are often curiously and beautifully present in the same crystal. They frequently penetrate the quartz crystals, and are also in the mica and in the albite, but the finest crystals are those from cavities or pockets, where they have had space to develop independently.[57] A description of the minerals found here is given by Bowman.[58]

Branchville

The lithium minerals occur in a pegmatite mass which is enclosed by mica-schist. A study of the schist shows it to consist of biotite, green hornblende, plagioclase feldspar, a little quartz, and some apatite, magnetite, and titanite. A second slide consists almost entirely of biotite and green hornblende with a little plagioclase feldspar. The contact of the pegmatite and schist is wavy. The former, just at the contact, is very rich in muscovite. The mica is here found in large masses several inches across. Otherwise the pegmatite contains a good deal of quartz, with some feldspar and but small quantities of muscovite. Spodumene is very abundant. Though several lithium minerals are abundant, tourmaline and lepidolite have not been mentioned as found here.

The following notes are taken from Brush and Dana's fourth Branchville paper[59] and present no new matter. The spodumene from Branchville, Connecticut, is, after the feldspars, mica and quartz, the most important of the original minerals of the locality, and occurs, though mostly in an altered condition, in very large quantities.

The greater part .of the unaltered spodumene occurs in confusedly crystalline masses, showing distinct cleavage, but seldom any approach to crystalline form. It is possible to obtain the mineral nearly pure, though somewhat intermingled with albite, in blocks weighing several hundred pounds. In this form the spodumene has a dull white color; it is in many cases somewhat discolored, and is only partially translucent; the cleavage surfaces are often coated \\'ith delicate dendrites of manganese oxide. The associated minerals, in addition to the albite and a little quartz and mica, are apatite, lithiophilite, columbite, garnet and uraninite, with various other uranium minerals formed from alteration.

In addition to this massive variety, the spodumene also occurs in an unaltered condition as nuclei of distinct pseudomorphous crystals. These crystals often occur of

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[56] Kunz, G.F., Mineral Resources U.S. for 1903, U.S. Geol. Survey, 1904, p. 926.

[57] Kunz, G.F., loc. cit., pp. 926, 927.

[58] Bowman, H.L, Mineral. Mag., May, 1902, vol. 13, No. 60, pp. 97-121.

[59] Brush, George, and Dana, Edward S., Am. Journal Sci., 3rd series, vol. 20, 1880, pp. 257-284.

enormous size, imbedded for the most part in massive quartz, though sometimes extending into the albite. The nucleus of spodumene is in every case sharply separated from the altered mineral surrounding it, and its characters show that the crystals must originally have had rare beauty. One of the finest crystals found had, as imbedded in the quartz, a length of three feet, a width of eight inches and a thickness of two inches. The unaltered spodumene, of a fine amethystine color, made up about one-fourth of the whole, extending rather regularly through the middle of the crystal. Unfortunately, the spodumene was much rifted and fractured, so that its former transparency had, for the most part, disappeared. The exterior of the crystal consisted principally of spodumene, with small quantities of cymatolite and albite. Another altered crystal was measured while imbedded in the quartz, of which a length of over four feet was exposed. It is not possible to extract these crystals entire, but many fragments have been obtained which have a width of over a foot across the prism and a thickness of two to four inches. In habit the crystals are generally broad or flat, through the development of the orthopinacoid, and comparatively thin; not infrequently they are well terminated. Occasional stout crystals, having a square prismatic form are also observed. In the better specimens the spodumene is perfectly transparent, sometimes colorless, and again of a beautiful rose-pink or amethystine-purple color. The alteration of this spodumene has been very minutely studied by Brush and Dana and reference is made to their original paper for a description thereof Associated with the soft, altered spodumene, is an interesting pink clay-like mineral, closely related to montmorillonite. It is most abundant in independent deposits of considerable extent in the vein not far from the point where the spodumene occurs. The pink clay forms soft masses, easily dug out with a spade, and enough of it was found in one spot to fill an ordinary cart.

North Carolina

The transparent green variety of spodumene, known as hiddenite, occurs in small veins traversing biotite gneiss, near Hiddenite in Alexander County, N.C. The veins contain quartz, calcite, dolomite, muscovite, rutile, black tourmaline, beryl, spodumene, pyrite, chalcopyrite and monazite. The calcite is later than the other minerals and fills up the veins at many places.

A tunnel 261 feet long was cut through the gneiss to a vein on which a shaft was then sunk. In 1882 the work on the vein had reached a depth of 36 feet, at which point the vein pinched out. Twelve pockets carrying beryl were found within an area of 40 feet square; four of the pockets contained also the gem spodumene. All these veins or pockets maintained nearly the same character of dip, thickness, length, and associations. In one instance a small pocket that contained two beautiful beryl crystals had its walls covered with large crystals of albite. A second pocket contained mica crystals except one small pellucid colorless beryl. In the rock-mining and in prospecting on the surface, the sign of a vein was the presence of small streaks of massive quartz or of mica, running in a direction counter to the strike of the country rock; they led to open pockets not many feet off. A large pocket extended in a nearly vertical direction for 20 feet, and was about one foot in diameter and four feet in its extreme lateral extent. The associated minerals were quartz crystals (from one ounce to 20 pounds in weight, some being fluid-bearing), green muscovite, rutile, dolomite, and small crystals of monazite. A fourth pocket, yielding ten ounces of fine green spodumene crystals, was a very narrow seam extending four feet in length in the partly disintegrated gneissic rock.

The green spodumene, or hiddenite, which is always transparent, ranges from colorless (rare) to a light-yellow, yellowish-green, then into deep yellow emerald-green.

Sometimes an entire crystal has a uniform green color, but generally one end is yellow and the other green. The finest crystal of hiddenite found measures 68 by 14 by 8 mm. One end is of very fine color and would yield a stone weighing perhaps 5-1/2 carats. Several smaller stones of good color ranging up to two carats have been cut. The cut stones sold for from 40 to 100 dollars a carat.[60]

Colorado

A large pegmatite mass four miles northwest of Canon City, Colorado, has been described by Sterrett[61] as containing lithium minerals. The pegmatite forms a low oval-hill and is surrounded by contorted biotite and hornblende gneiss. Black, pink, and green tourmalines with scaly pink masses of lepidolite are found here. The locality is of especial interest as the mineral natramblygonite was described from here.[62]

Alaska

On Cassiterite Creek, near Cape York, Alaska, zinnwaldite occurs as a vein cutting through limestone. Some veins consist almost entirely of zinnwaldite; others show the mica scattered through massive quartz. Cassiterite, fluorite, feldspar, calcite, tourmaline (black) topaz, pyrite, garnet, galena, wolframite and malachite are mentioned as associated minerals.[63]

Foreign Occurrences

Sweden.

Uto.

At Uto, in a magnetic vein in gneiss, are found red, green and blue crystals of tourmaline, often in aggregates with lepidolite, quartz, and reddish feldspar. Indigo blue prisms are sometimes enclosed in petalite. Large greenish-white, tabular masses of spodumene occur in quartz, and petalite is found in coarse-grained to compact, milk-white to grey, greenish, and reddish masses, often in fairly large pure pieces.[64]

Germany.

Saxony.

In the granitic region of Penig, near Limbach, Hartmannsdorf, Kleinchursdorf,

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[60] Kunz, G.F., Gems and Precious Stones of North America, 1892.

[61] Sterrett, D.B. The Production of precious stones in 1908; Mineral Resources, 1908, U.S. Geol. Survey, 1909, p. 44.

[62] Schaller, W.T. Natramblygonite, a new mineral. Amer, Journal of Science., 4th series., vol. 31, pp. 47-50, 1911.

[63] Collier, A. J. The tin deposits of the York region, Alaska. Bull. U.S. Geol. Survey No. 229, p. 20, 1907. See also Schaller, W.T. Mineralogical Notes, Bull, U.S. Geol. Survey, No. 262, p. 129, 1905; Mineralogical Notes, Series 1, Bull. U.S. Geol. Survey, No. 490, p. 98, 1911.

[64] Hintze, Handbuch d. Mineralogic, vol. 2, p. 350.

Rochsburg, and Mylau, tourmaline and lepidolite occur in cavities of the granite. The tourmalines are black, red, green, blue, and white; single crystals are often multicolored, the end by which they are attached to the rock being usually black. The other minerals present are quartz, orthoclase, albite, topaz, amblygonite, and lepidolite, the latter mineral occurring as large rose red plates with irregular outline, on the edges of which are often druses of tourmalines. It also is present as scaly masses of a pink color.[65]

At Wolkenburg, tourmalines were found in a vein of tourmaline granite (pegmatite?) in granulite. This vein is composed of flesh-colored orthoclase, oligoclase, granular and prismatic quartz, muscovite in single plates and radiating aggregates of plates, and abundant black tourmalines, sometimes hollow and more or less filled with quartz and feldspar. Light-green tourmalines are often intergrown with the bunches of muscovite. Cavities in the vein are filled with druses of coarse red lepidolite, greyish-white quartz, pink orthoclase, radiated groups and single prisms of light to dark-red, even cherry-red, green, and yellowish tourmalines. The dark-red ones are usually associated with quartz, the deep green brittle crystals being found only in feldspar. Many of these tourmalines are more or less completely changed to impure muscovite. The lepidolite occurs in coarse plates, reddish grey to peach-blossom red, and also in prisms, a centimeter wide and half as high, with the edges replaced by small planes.

White to pink lithia mica has been found near Radeburg, in the tunnel of Oberau, and near Mittweida in fine scaly masses of a greenish white color. At Altenberg, zinnwaldite is found in veins in granite and gneisses.

Austria.

Silesia.

In cavities of the granite at Striegau are found red, greenish-brown and black tourmalines imbedded in lepidolite flakes or lying on quartz and feldspar, also enclosed in feldspar. The lepidolite occurs on albite as white plates, which easily give a lithia flame reaction. At times it is covered with a pale yellowish green warty coating consisting of acute rhombic plates. It also encloses tourmaline.[66]

Bohemia.

At Schattenhofen[67] on the right bank of the Wottawa, a deposit of pegmatite occurs enclosed in a magnesian limestone (16 per cent MgO). The line of contact is very sharp and well defined, there being no igneous zone of contact. This pegmatite has been exposed for a length of about ten feet and a width and thickness of four feet, and the following three zones of mineral associations have been described.

The first zone lies directly against the limestone and is composed of quartz, microcline, lepidomelane, silver white to a brown muscovite; it also contains apatite, monazite, and xenotime, but seems to be fairly free from tourmaline.

The second zone contains quartz, white albite, yellowish-white muscovite, brown manganese- garnet, and blue-black tourmalines, rarely light-green, then enclosed between plates of muscovite, rarer in quartz or albite. The blue-black tourmaline is the oldest member of this zone and occurs in more or less well developed crystals. Those nearest the first zone have a holohedral hexagonal cross-section, while those in the

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[65] ibid., p. 333, 594

[66] Ibid., p. 336.

[67] Zeit.f.Kryst., vol. 13, p. 451; Hintze, Joe. cit., p. 338, 594.

remaining part of the zone have a trigonal cross-section; they are often bent and frequently broken, forming cracks which have become filled with quartz or more rarely with albite. Some single crystals possess a central core of greyish white quartz, striated like the surrounding tourmaline and following all the mechanical deformations of the latter mineral without breaking. The thicker, light-green, sometimes greyish-green, crystals often possess a darker core of grass-green to blue-green.

In the third and youngest zone occur quartz, tabular bluish white albite (cleavelandite), lepidolite, dark-green and rose-red tourmalines. The dark-green tourmalines show all sorts of gradations in color with the blue-black and the red, and occur only in combination with these colors the lower older end being usually blue-black or deep blue-green, the upper and youngest end being red. The thicker red crystals, of trigonal habit with no observed terminations, also occur in lepidolite or in a matrix of lepidolite and quartz. Sometimes they are grown together with the darker colored tourmalines. The lepidolite occurs on the albite or intergrown with the quartz as scaly masses consisting of plates without any regular outline. Lepidolite frequently forms a border around the greenish-white muscovite so that both micas can be cleaved off together.

At Zinnwald[68], zinnwaldite is found in veins in greisen, associated with quartz, cassiterite and fluorite.

Moravia.

Outcropping on the summit of Mt. Hradisko, a ("Salband") body of massive lepidolite, 6 feet thick, lies between a quartz-rich pegmatite and the quartz-poor granulitic gneiss which surrounds the pegmatite. This is the only foreign locality of lepidolite which has been commercially worked. The lepidolite occurs in long six-sided plates and, more commonly, in scaly to compact masses, dark to light purple-red, rarely also green, blue-violet, and blue-green, associated with topaz, apatite, wolframite (in green lepidolite), cassiterite, orthoclase, quartz, and tourmalines. The latter occur in radiated aggregates, and in 3-, 6-, or 9-sided prisms of various shades of red, rarely with definite end terminations and usually only half transparent, also passing into blue, violet, green, yellow, and brown. Many crystals are green at one end and red at the other. Leek-green, radiated aggregates occur in blue violet lepidolite; blue crystals are also imbedded in lepidolite. Red, blue, and green tourmalines are also enclosed in quartz.[69]

Russia.

Near Juschakowa, 6 km south of Mursinka, lilac plates of lepidolite, of irregular outline and reaching a diameter of 5 cm. are found in a coarse-grained granite together with snow white albite, greyish-white quartz and yellow beryl.

Cavities in the coarse granite at Jekaterinburg, near the village of Alabaschka about 8 km. from Mursinka, contain large reddish plates of lepidolite up to 7 cm. in diameter and also compact masses with large yellow orthoclase crystals, white transparent albite, greyish quartz, colorless topaz, light grey-brown mica, garnet, beryl microlite and tourmaline.

At Sarapulka, 12 km. from Mursinka, gem tourmalines are found in the surface

[68] Miers, Mineralogy, p. 478.
[69] Hintze, loc. cit. pp. 340, 594.

soil mixed with disintegrated granite on the eastern slope of a granite (rise) hill. The crystals are mostly small, of a deep red color, at times with a dark violet-blue core, also blue to indigo-blue, dark blue-green to blue- black.[70]

In the neighborhood of Schaitanka, 48 km. south of Mursinka, tourmalines occur in the cavities of a coarse-grained granite, composed of yellowish-white orthoclase, greenish-white albite, greyish-white quartz, and greenish muscovite. Lilac lepidolite is also present, and at times forms a narrow border on yellowish white muscovite. The tourmalines are imbedded in the feldspar and lepidolite and are also found loose in a yellow clay. They are colored light to dark-red, violet-blue, light olive-green, light liver-brown, and blackish-brown. Most of the crystals are multi-colored, the two ends being usually of different colors. Only the smaller ones are transparent.

Near the village of Schabrov green tourmaline is found, which, like alexandrite (a green variety of chrysoberyl), is said to change its color from pure green in natural light to ruby-red in artificial light.[71]

The general character of the coarse granite which is the home of the Russian tourmaline and lepidolite is essentially that of a pegmatite which is probably much disintegrated.

Italy.

Elba.

The granite veins (dikes) of San Piero in Campo, Elba, which have a north and south strike and a dip of 50°-90° and which occur by the thousand from a mere sheet a few millimeters wide to much thicker ones, contain colored tourmalines, lepidolite, and other lithia minerals. The veins are usually in granite but at times run into a schist. Near the edge of the veins, black tourmalines are present, while some veins, a few inches thick, are snow-white except for the occasional nests of tourmalines.[72]

A description by G. von Rath[73] of one of the veins shows that there is a band about 16 centimeters thick on both sides, consisting of black mica crystals. For the next 8 centimeters the mica is smaller and is arranged normal to the walls of the ledge. Then comes graphic granite for 2 centimeters, and the inner layer from 2-5 centimeters thick is composed of crystals of feldspar, quartz, tourmaline and lepidolite. The lithium minerals occur in the central part of the veins. Not all the veins contain lithium minerals, nor do such as contain them have them throughout their entire lengths. Two neighboring veins may unite and, further on, may separate again. The lithia tourmalines, beryl, lepidolite, etc., are foreign to the normal granite in which these veins occur. A. Fersman[74] has recently given an interesting description of these occurrences and Prof. F. Slavik of Prague, Bohemia was so very kind as to furnish me with a partial translation of Fersman's paper from which translation the following brief notes are culled.

The granite magma of the Mt. Capanne massif is chemically nearly homogeneous throughout its entire extent but structurally it changes at various places. At the contacts \\ith the slates, etc., the granite becomes porphyritic with large feldspar crystals. Hundreds of pegmatite and aplite dikes, rich in tourmaline, cut the granite.

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[70] Ibid., pp. 351, 595

[71] Kunz:, G. F. Mineral Resources, U.S. Geol. Survey, 1902.

[72] Hintze, loc. cit. p. 345.

[73] G. von Rath. Die Insel Elba. Zeitschr.d.d.geol. Ges., vol. 22, 1870, p. 1870

[74] Fersman, A. Contributions to the mineralogy of Elba: Bull. de la Societe des naturalistes, Moscow, 1909. (In Russian).

Their contacts are not sharp and seem to be a product of magmatic differentiation formed at the time the magma was cooling and not as later intrusions. The largest amount of such elements as Li, Cs, Rb, F, Cl, H2O, Mn, is concentrated in the upper part of the dike. Thus black and green tourmalines are found in the lower part of the dike, whereas pink tourmaline is more abundant in the upper portion. Similarly blue and white beryls are found in the lower part but the caesium beryl (worobieffite) occurs chiefly in the upper part.

The symmetrical structure of the dikes is as follows:
1. Common granite.
2.   More leucocratic granite.
3.   Narrow zone rich in biotite.
4.   Coarse--granular aggregates of biotite, quartz and feldspar.
5.   Aplite.
4.   Coarse granular aggregate of biotite, quartz and feldspar.
3.   Narrow zone rich in biotite.
2.   More leucocratic granite.
1. Common granite.

Many of the dikes are not especially interesting mineralogically. These have the black tourmalines concentrated on the edges; pink tourmalines are rare.

At two localities the succession of minerals is as follows:

Grotta d'Oggi.	Fonte del Prete and Cave della Speranza
1. Quartz, orthoclase, black tourmaline.	1. Quartz, orthoclase, and black tourmaline
2. Quartz, orthoclase, polychromic tourmaline	2. Quartz, orthoclase, and polychromic tourmaline
3. Quartz, albite, polychromic tourmaline	3. Quartz, albite
4. Quartz, albite, garnet-tourmaline rare.	4 Quartz, albite, petalite, and pink tourmaline
5. Quartz, albite, beryl-tourmaline rare.	5. Pink tourmaline, common quartz rare
6. Quartz, albite, lepidolite -I, tourmaline	6. Pink beryl, pink tourmaline, and quartz rare
7. Quartz, albite, black tourmaline-rare.	7. Lepidolite-II, pink tourmaline, and quartz rare
8. Quartz, albite, chabazite-tourmaline rare.	8. Pollucite, pink tourmaline and quartz rare
9. Lepidolite II, apatite	
10. Chabazite.	
11. Stilbite.	
12. D'Archiardite.	
13. Foresite.	
14. Heulandite.	
15. Laumontite.	

These successive generations show transitions from one to the other excepting between Nos. 8 and 9 where the boundary is sharp separating the period of formation of the pegmatite dikes themselves from that of the genesis of the secondary minerals:

zeolites, lepidolite II (second generation) and apatite. Quartz, feldspar, beryl, lepidolite I, pollucite, petalite, all show signs of alteration and corrosion. The secondary processes yielding the above named results are not later infiltrations but a direct continuation of the processes of the dike formation.

The larger veins have cavities in them, containing milk-white orthoclase, albite, quartz, silver- white to pink mica, yellow-red garnets, "With colorless, pink or whitish beryl, and black, green, red, colorless, and many other colored tourmalines. Black tourmalines are the commonest and often are very abundant; the red colored are mostly pale pink, very seldom deep red; the green ones show gradations in color, the free end being red and often paler than the remainder of the crystal, the attached end being frequently green or bluish green.

Petalite occurs particularly in the veins at Speranza, often imbedded in the yellowish-white hydropetalite, in water clear to greyish-white crystals, often etched. Orthoclase, albite, quartz, lepidolite, tourmaline, garnet, cassiterite, microlite, beryl, hematite, and pollucite are associated with it.

An unusual but probably secondary mode of occurrence of a lithium mica is that described by Colomba[75] who found the mineral as microscopic flakes abundant in anhydrite and gypsum. The uniaxial mica gave an analysis:

SiO_2, 42.40;
Al_2O_3, 12.66;
MgO, 20.10;
CaO, 6.76;
Li_2O, 5.21;
K_2O,
Na_2O, 4.68;
volatile elements, 6.82;
total, 98.63.

France.

In the Central Plateau region of France, pegmatites with lithium minerals are abundant at Montebras in Creuse, at Hureaux and Chanteloube in Haute-Vienne, and several other places. At Montebras, prehistoric excavations in the pegmatite were uncovered in 1859 and as tin was doubtless and metal searched for, new excavations were extended downward for nearly 500 feet but the enterprise was abandoned in 1877.

Since 1886 about 100 tons of amblygonite were produced annually which was used in the glass industry replacing calcium phosphate. The pegmatite containing the amblygonite and cassiterite and much apatite forms very irregular dikes in a granulite. The locality also produces clay, feldspar and quartz in commercial amounts.

Brazil.

In the province of Minas Gerais tourmaline is found as loose pieces, usually green, rarely black, and at times pale-red to colorless. Green prisms 1-1/2 inches long and one-half inch thick are found with white and blue topaz. Blue tourmalines also

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[75] Colomba, L. Ricerche mineralogiche sui giacimenticidi anidrite e di gesso dei di ntorni di Oulx (Alta Valle della) Dora Riparia: Atti della R. Accad. Sclenze Torino, -ot. 33, p. 786, 1897.

occur. The yellowish-green spodumene (triphane) occurs here as loose pieces in the disintegrated rock. A transparent blue variety[76] has rarely been found in Rio San Francesco in the neighborhood of Diamantina in Minas Gerais.

Australia.

Lithium minerals are found abundantly in Western Australia, round the outskirts of granite masses. A few miles west of the Londonderry gold mine, Coolgardie goldfield, and close to the junction of the granite and amphibolite, are several dikes of very coarse-grained granite (pegmatite) traversing the latter. These dikes are composed mainly of quartz, orthoclase, lepidolite, and topaz. One of the dikes has been opened by a quarry to some depth in order to extract the lithia mica. This mica is of amethystine color and has been obtained in sheets as large as 15 inches long by 12 inches.

About half-a-mile of Ravensthorpe there is a dike of tourmaline granite, carrying large prismatic crystals of apple-green spodumene.[77]

Malay Peninsula.

The following extract taken from a paper by J.B. Scrivenor78 describes an unusual mode of occurrence of lithia-mica but the identification of the mineral as a lithia-mica and its association, etc., needs verifications.

"Quite lately I took from Siputeh [Malay Peninsula] some dark crystalline limestone in order to determine whether carbon were present or not. After dissolving away the calcite and burning off the carbon found in the residue, I found I had left a pale pink mass of lithia-mica and tremolite."

Madagascar.

The pegmatites of Madagascar occur in bedded limestones, schists or in granite. Those in limestone generally follow the laminations of the sedimentary rock though they may become very irregular in their thickness as shown in figure 33.

Figure 35 Occurrences of pegmatite in Madagascar. After Duparc

The gem minerals are abundant and are found in large geodes in the limestone. The list of minerals found here is very extensive, nearly a dozen new species having been described.

Part IV: Description of minerals

General Classification.

The minerals found in the pegmatites of the gem tourmaline field of southern California are remarkable not for the large number of species but for the wonderful

[76] Bauer, Edelsteinkunde, p. 513.

[77] Simpson, Edward S. Bull. Geol. Survey West. Australia, No.6, Perth, 1902.

[78] Scrivener, J.B., The origin of tin deposits: A. paper read before the Perak Chamber of Mines, 23rd January, 1909, Ipoh. Separate, 11 pp., 1909, p. 10.

development and exquisite beauty of several of the species. The specimens of kunzite, rubellite, lepidolite, and beryl are unrivaled for their beauty and perfection of development. The specimens of minerals of the columbite group- manganocolumbite and stibiotantalite-will bear comparison with those from any other known locality. The alterations also are interesting, that of bismuth yielding bismite, pucherite, bismutite, and bismutosphalerite, and that of lithiophilite- found in large crystals-yielding the four new minerals, palaite, salmonsite, stewartite, and sicklerite, besides hureaulite, strengite, purpurite, manganite, and psilomelane.

Fifty-three mineral species are described in the following pages. The order of description is based on the order used by Dana in his System of Mineralogy, 6th edition, and the minerals are as follows:

DID NOT TYPE TABLE.

These same minerals are also grouped according to their origin, namely, according as they are primary minerals of the pegmatite, that is, have not changed in chemical composition since their first solidification in the pegmatite; or according as they are secondary minerals, that is, have changed in chemical composition since their first solidification in the pegmatite. The changes by which the secondary minerals were formed are of two kinds-(1) a magmatic change taking place in the magma before the entire pegmatite had solidified and (2) a weathering change taking place after the entire pegmatite had solidified and due to causes having no genetic relation to the pegmatite but due to the effects produced by the atmosphere with its contained water, oxygen, and carbonic acid.

On this bases of division the 53 minerals are grouped as follows:

DID NOT TYPE TABLE.

A geographic grouping of the minerals would be a most interesting one, but to be of much value should be complete, that is, every mineral found at every locality should be known, and this is obviously impossible in a situation like the one in California, where the work is sporadically undertaken and the minerals found are scattered broadcast without any record being kept of them. It is manifestly unfair therefore to state that a certain mineral was found at one place and not at a second place, whereas the mineral may have been obtained in quantity at the second place but the writer is not aware of it. Then too the indications always are that the occurrence of a mineral is much broader than the available specimens show. Native bismuth for example has been found to the writers knowledge only at Pala and at Rincon; yet the stibiotantalite from Mesa Grande contains bismuth and it is therefore presumable that native bismuth may also occur at Mesa Grande. So too, stibiotantalite has been found at Ramona. Presumably this likewise contains bismuth and presumably therefore native bismuth may also occur at Ramona. Of four localities, native bismuth is known to the writer from only two, yet the indications are that it probably occurs at all four.

The geographic distribution given below is based on the writer's knowledge of the occurrences, but, as suggested in the preceding paragraph, it is correct only on its positive side. The negative side, that is, the statement as to a mineral that it does not occur at a locality, may be erroneous. Some of the locality occurrences reported in various publications are known to be erroneous, as the writer has had opportunity of examining the specimens on which the determinations were made.

The following minerals are to be found at all the pegmatite exposures examined:

quartz, orthoclase, microcline, albite, spessartite (garnet), schorlite (black tourmaline), muscovite, and biotite. The minerals hematite, limonite, manganite, psilomelane, chlorite, epidote, chrysocolla, and the clays, halloysite, kaolinite, etc., represent unimportant and uninteresting alterations and are omitted.

DID NOT TYPE TABLE   OR   PLATE PAGE

Bismuth

localities

Metallic bismuth has been found at Pala and at Rincon. In addition to these places bismuth is present in combination, but not as the metal itself, in stibiotantalite from Mesa Grande. This stibiotantalite contains, according to the analyses by Penfield and Ford, a small quantity of bismuth sulphide. It is probable, though not proved, that the stibiotantalite of Ramona likewise contains a little bismuth.

At Pala, native bismuth has been obtained at the Stewart mine and at the Tourmaline Queen mine. The presence of its oxidation product, the so-called bismuth ocher, at the Pala Chief mine and at several places on Hiriart Hill makes it very probable that metallic bismuth also occurs at these places. In fact, Mr. F.M. Sickler reports bismuth as having been found on Hiriart Hill. At Rincon, bismuth was collected at the Victor mine by Prof. A.F. Rogers, of Stanford University. The presence at Rincon of bismuth ocher had been earlier determined on specimens sent in by Mr. F.M. Sickler.

Occurrence.

Bismuth has been found only in the pay shoot of the lithium-bearing pegmatite dikes, and at the Tourmaline Queen and the Victor mines it is directly associated ·with the lithium minerals lepidolite and tourmaline. In its mode of occurrence it strongly suggests a primary mineral of the pegmatite, on a par, genetically, with the quartz, feldspar, and mica. It is always crystalline and has a good cleavage but does not show crystal boundaries.

The large masses found at the Stewart mine weigh several pounds and consist of distinct crystalline masses, differently oriented, as can be readily seen by the variously oriented cleavage faces formed by breaking a specimen. Some of these single cleavage faces measure several centimeters across. No specimen was seen which indicated a replacement of some other mineral (feldspar, for example) as suggested by Kunz.[79] Several pieces of the metallic bismuth from the Stewart mine were tested qualitatively for vanadium, but none was found.

The larger masses of bismuth are not intermingled with any other primary mineral. It was also noted in the Stewart mine as small particles disseminated through much of the massive quartz immediately surrounding the large body of amblygonite now removed. It is reported to have been occasionally found in the amblygonite and, in fact, this mineral was said to carry a trace of bismuth. All of the larger pieces of bismuth are coated with variously colored oxidation products, the so-called bismuth ochers.

A specimen (No.   ) from the Tourmaline Queen mine shows well the mode of derivation of the bismuth ochers. The metallic bismuth here forms the residual core of a mass of bismuth carbonate (bismutite) measuring about 6 by 3 millimeters. This is

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[79] See Bibliography, p. x for reference.

surrounded by yellow stains of bismuth ocher, derived from the carbonate. The relations are diagrammatically shown in figure 36. From the relations shown on the different specimens, it is clear that the metallic bismuth is the original mineral from which all the other bismuth minerals except the sulphide, are derived.

Figure 36 Diagrammatic relations of bismuth, bismuth carbonate (bismutite), and bismuth ocher (impure pucherite).

The specimens from the Victor mine, at Rincon, show the bismuth as small rounded blebs, millimeters in diameter. These are embedded in a deep-blue lepidolite and are accompanied by similar secondary bismuth minerals as at the Tourmaline Queen mine.

Alteration.

The alteration of the metallic bismuth has yielded a series of minerals comprised under the general term "bismuth ocher", which is generally used to designate the mineral bismite, supposed to be Bi_2O_3. A review of the literature on bismite or bismuth ochers free from carbonate shows only two analyses on which the existence of the natural anhydrous oxide of bismuth is based. The first is by Suckow[80] (1848), who gives the composition of bismuth ocher, free from water and carbonic acid, as follows: Bi_2O_3, 96.5; As_2O_3, 1.5; brown iron ore, 2.0; total, 100. The analysis is certainly far from satisfactory. The second analysis is by Camot[81], who gives 96.70 per cent Bi_2O_3 with the remainder distributed over eight compounds, including 0.95 per cent H_2O, also SO_3, HCl, CO_2, etc. Although it indicates the probable presence of Bi_2O_3, the existence of the simple oxide can hardly be considered as established by the analysis of Carnot.

The first natural crystals of bismite described do not agree[82] with those artificially prepared and it seems doubtful whether Bi_2O_3 actually occurs in nature. The apparent identity of the natural crystals described by Rogers with the artificial crystals of Bi_2O_3 is rendered somewhat questionable by the lack of chemical data on his crystals and by the evidence of the composition of these ochers as herein set forth.

The presence of the bismuth ochers, which have been called bismite, has also been noted by Kunz and Rogers.

It being shown that it is not at all certain that bismuth ocher is Bi_2O_3, it seems far preferable to use the term bismuth ocher in a more general sense and to let it comprise a group of secondary bismuth minerals, which are generally not distinctly crystallized. It is in this last sense that the term is here used. The bismuth ochers found in this area include bismutite, bismite, pucherite, and probably bismuthinite and bismutosphaerite.

In describing the occurrence of bismuth at the Tourmaline Queen mine, it was said (and illustrated in figure   ) that the immediate mineral resulting from the alteration of the bismuth was bismutite and that from this carbonate the yellow bismuth ocher-the so-called bismite-resulted. This last oxidation product consists of bismuth hydroxide or bismuth vanadate or mixtures of the two. (See below under bismite and pucherite.) The changes resulting in the formation of these bismuth ochers consist of

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[80] See Hintze, C., Handbuch d. mineralogic, vol. 1, p. 1246, 1904, for references.

[81] See Hintze, op. cit.

[82] Schaller, W.T., and Ransome, F.L., Bismite: Am. Jour. Sci., 4th ser., vol. 29, p. 173, 1910.

two distinct stages; first, a change from metallic bismuth to a hydrous carbonate, probably caused to a large extent by the action of meteoric water and of the air; second, a reaction between this hydrous carbonate and solutions containing vanadic acid or some vanadate. The vanadium was probably derived from the gabbro surrounding the pegmatite, which, in a fresh condition (specimen No.), was found to contain 0.01 per cent V_2O_5. The two reactions indicated may be represented as follows, though the equations are, of course, only suggestions:

$$Bi_2 + H_2CO_3 + O_3 = H_2Bi_2CO_6 \text{ (bismutite).}$$

$$H_2Bi_2CO_6 + 2H_2O = CO_2 + 2Bi(OH)_3 \text{ (bismite).}$$

$$(2)\ H_2Bi_2CO_6 + 2H_3VO_4 = 4H_2O + CO_2 + 2BiVO_4 \text{ (pucherite).}$$
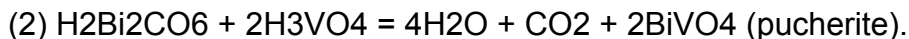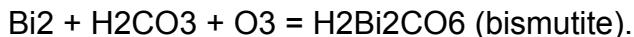
Under suitable conditions both the reactions shown under (2) may proceed together and the result is the formation of such mixed ochers as the yellow ocher from the Stewart mine. (See below under pucherite). These mixed ochers may, of course, also have been formed by the commingling of solutions containing bismuth hydrate and bismuth vanadate.

Bismite

The formula of bismite being in doubt I have provisionally referred to it a single specimen from the Stewart Mine at Pala.

A specimen of quartz from the Stewart mine, Pala, showed a thin coating of a grayish material containing a few yellow spots. This coating proved on examination to be bismuth hydroxide. The gray ocher became yellow on ignition and retained the yellow color on cooling, though some spots had a greenish color. On the addition of cold nitric acid to the ignited material it became white. These color reactions are different from those of the yellow ocher or pucherite, described beyond.

A quantity of the material was scraped off with a knife but only 0.0953 gram of the substance would be obtained. This was massive, opaque, and noncrystalline, as determined by examination under the microscope. An analysis made on this small quantity gave the following values:

Analysis of gray bismite,
Stewart mine, Pala, California
W. T. Schaller, Analyst

	Bi2O3	64.9
	V2O5	.8
Gangue	sol in HNO3	9.5
	insol in HNO3	13.5
	at 107°	.4
H2O	at 240°	.3
	on ign	11.4
		100.8

As the analysis shows, only a small amount of vanadium is present and this is doubtless due to the presence of a little pucherite, as shown by the small yellow spots in the original sample. Besides the gangue only bismuth oxide and water are present, and this gray bismuth ocher is doubtless a bismuth hydroxide. Before considering the ratios, however, a little water should be deducted for the gangue soluble in HNO3, which is probably a clay comparable to the halloysite occurring here so abundantly. This halloysite, as shown by the analysis on p.   , contains nearly 19 percent of water, of which one- third is given off at 107°. Assuming that the 9.5 per cent of soluble gangue was ignited halloysite, there would be about 2.2 per cent of the total water of the bismite analysis belonging to this gangue. As some water was also given off by the insoluble gangue it may be safely assumed that nearly 3 per cent of the total water found belonged to the gangue and not to the bismuth ocher. Readjusting the analysis on this basis we have the following values.

Readjusted analysis and ratios of gray bismuth ocher,
Stewart mine, Pala, California.

Analysis.		Ratios.						
Bi_2O_3	64.9	0.140	-	0.004	=	0.136	=	1.0
V_2O_5	.8	.004	-	.004	=	-		
H_2O(ocher)	9.1	.506			=	.506	=	3.7
H_2O(gangue)	3.0							
gangue	23.0							
	100.8							

The ratios agree fairly well with the formula BI2O3.3H2O, the quality and quantity of material analyzed and the uncertain nature of the assumptions made with regard to the water of the gangue being considered. The gray bismuth ocher may then be classed as a bismuth hydroxide (Bi(OH)3), to which the name bismite should be given, as the anhydrous bismuth oxide (Bi2O3), has not yet been definitely proved to exist in nature.

Some of the greyish, greenish, or yellowish coatings on the metallic bismuth from the Stewart mine are free from vanadium, as far as could be determined on the minute quantities of material available. They probably represent bismite or, to a less extent, bismutosphaerite.

Pucherite

The rare mineral pucherite has so far been found in this field in a pure state only in the Pala Chief mine. Mixed with bismite (that is, the bismuth hydroxide ($Bi(OH)_3$) it is much more common, being found wherever native bismuth was detected, and also at several additional localities. This ocherous oxidation product is found coating the quartz and other minerals of the pegmatite as grey, yellow or green pulverulent masses, usually in very limited quantities. Examination under the microscope showed it all to be opaque and without crystal boundaries. Nothing indicated, however, that the material was not homogeneous.

Pucherite was found at several mines at Pala. These are the Stewart (most abundant) and Tourmaline Queen mines on Stewart Hill, the Pala Chief mine (nearly pure) on Pala Chief Hill, and the Hiriart Mine on Hiriart Hill. It has also been reported from the Katerina and Vanderburg-Naylor mines.

At Rincon it occurs at the Victor mine, and it is in this material that the supposed crystals of Bi_2O_3 were found by Rogers.

Chemical composition.

Two different samples were analyzed, both from Pala but from two different mines. The first sample was nearly pure pucherite, while the second one was mixed ·with bismite. The yellow ocher became dark red-brown on ignition, and the grey bismite turned yellow on being heated, as previously described.

The method of analysis was as follows: The mineral was heated in a porcelain crucible at different temperatures (as given) to constant weight and finally ignited by a low flame. The water was thus determined by loss, but its presence and the absence of carbonic acid was determined qualitatively for each sample analyzed. The ignited mass was dissolved in HNO_3, the insoluble residue filtered off, and the bismuth precipitated by H_2S. The bismuth was finally precipitated as carbonate and weighed as Bi_2O_3. The combined filtrates containing the vanadium were evaporated to dryness and the vanadium and soluble gangue weighed as a check on the subsequent determinations. The vanadium was then separated by a current of dry HCl gas; the vanadium oxychloride formed was collected in water and, after evaporation with H_2SO_4, was reduced and titrated with permanganate. The residue from which the vanadium was driven off by HC1gas was ignited and weighed as the residue soluble in HNO_3. It consisted chiefly of silica and alumina with some lime.

A sample of coherent yellow ocher was found at the Pala Chief mine which resembled that from the Stewart mine in almost every way. Very unexpectedly the composition of this sample was found to be that of purcherite, $BiVO_4$. A fifth of a gram gave, on analysis, the results shown below:

Analysis and ratios of pucherite,
Pala Chief mine, Pala, California
W.T. Schaller, analyst.

	Analysis.		Ratios.
	Bi2O3	66.14	0.143
	V2O5	25.80	.142
	Insol. gangue	7.37	
	at 107°	.21	
H2O	at 240°	.32	
	on ign.	.84	
		100.68	

The ratios yield sharply the formula Bi2O3 • V2O5, which is the mineral pucherite. The small amount of water retained about 107° may have come from the insoluble gangue. This occurs to be the first occurrence of pucherite noted in the United States.

The yellow ocher from the Stewart mine is the most abundant and nearly a gram of it was obtained for analysis. About a quarter of it was sacrificed for qualitative tests, which showed the presence of an insoluble residue (mostly quartz and feldspar) and, in the solution, of abundant bismuth and vanadium and of very small quantities of silica, alumina, and lime. A small amount of water was given off when the ocher was heated in a closed tube. No carbonic acid was given off on dissolving the mineral in HC1, and bases other than those mentioned could not be detected in the solution.

The quantitative analysis of the yellow bismuth ocher from the Stewart mine gave the following values, the ratios obtained there from being also given.

Analysis and ratios of yellow, bismuth ocher,
Stewart mine, Pala, California.
[W.T. Schaller, analyst.]

Analysis		Ratios				
Bi2O3	64.43	0.139	or	2	by	0.0695
V2O5	12.11	0.067	or	1	by	.067
Gangue sol. in HN03	2.27					
Gangue insol. in HNO3	17.63					
H2O at 107°	0.32					
H2O at 210°	0.24°	0.204	or	3	by	.068
H2O on ignition	3.43					
Total	100.43					

The ratios yield sharply the formula 3H2O • 2Bi2O3 • V2O5• which may be interpreted as BiVO4 • Bi(OH)3, forming a basic hydrous bismuth vanadate.

On the chemical evidence thus obtained, one would be almost justified in describing this yellow ocher from the Stewart mine as a distinct new mineral species with the formula just given. In fact, many new (supposed) species have been proposed on evidence weaker than that here shown. It is however, more simple and probably nearer the truth to regard this ocher as a mechanical mixture of pucherite and bismite (Bi(OH)3). The yellow color of the pucherite would so mask the gray bismite that it could not be detected in the mixture.

Bismutosphaerite.

One specimen of bismuth from the Stewart mine gave a minute quantity of a prismatic aggregate which, on qualitative tests, yielded only bismuth and carbonic acid and seemed to be anhydrous. Its determination as bismutosphaerite was made on the basis of the chemical tests cited.

A second specimen of altered tourmaline from the Stewart mine contained an aggregate of minute fibrous crystals, which when tested chemically gave reactions for bismuth and carbonic acid. Neither vanadium nor water was present. Examined under the microscope, the fibers were seen to be terminated, but the individual facets were too minute for accurate determination. One fiber was terminated by a plane normal to the elongation, as shown in figure 35a. A second crystal (fig. 35b) showed the horizontal terminal plane and in addition other inclined faces. A third group of crystals, well terminated at both ends, showed only the inclined terminal faces, probably those of a pyramid. This group is shown in figure 37c. The angle between the prism zone and the inclined plane is about 66°.

Figure 37. Microscopic crystals of bismutosphaerite. A terminated by a plane normal to the elongation; b, a crystal terminated by both horizontal and inclined planes; c, a group of doubly terminated crystals.

The crystals are pale yellow in color, extinguish parallel, and are only slightly pleochroic in shades of yellow. Parallel to the elongation the color is deeper yellow than normal thereto. The birefringence is high. The elongation is positive.

Bismuthinite.

The presence of bismuthinite (Bi_2S_3) could not be definitely determined, but its presence is strongly suggested by the following test. To a sample of bismuth minerals (from the Stewart mine) in a test tube was added HCl and the treatment with lead acetate paper showed that H_2S was being given off. This test was confirmed several years later, and a sulphide was detected in the bismuth minerals from the Stewart and Tourmaline Queen mines, at Pala, and from the Victor mine, at Rincon. Nothing that suggested the presence of bismuthinite could be seen, however, on any of the specimens.

Bismutite.

Bismutite, the hydrous bismuth carbonate ($Bi_2O_3 \cdot CO_2 \cdot H_2O$) has been found at the Stewart mine and at Rincon. At the Stewart mine it was obtained as small pieces of massive gray mineral, having a dull luster and containing admixed bismuth and yellow bismuth ocher (pucherite). The material was too poor in quality to warrant any quantitative analysis so it was determined by its qualitative reactions. It dissolves readily in acids with brisk effervescence and when heated in a dosed tube decrepitates and gives off water. Careful tests made on pure fragments showed that no vanadium was present in the bismutite.

Pyrite.

Pyrite is occasionally found in the gabbro surrounding the pegmatite ledges and forms an accessory mineral (often with pyrrhotite) of the gabbro. A cube of limonite, pseudomorphous after pyrite, was stated to have been obtained from the pegmatite at the Himalaya mine, Mesa Grande. It may be, however, that the mineral came from the surrounding gabbro, as pyrite and pyrrhotite were seen at several places in the gabbro of Mesa Grande.

A specimen of pyrite was collected at Pala which, from its associations, seemed to have come from pegmatite. It was not found in place, but a few specimens were lying on the dump of prospect No. 46, Stewart Hill, Pala, with the quartz and feldspar of the pegmatite. The pyrite forms a mass of sulphide 4 centimeters across and shows striated crystal faces but no distinct crystals. The outside of the specimen is altered to iron oxides and the associated feldspar is also much altered. Several pieces of altered pyrite were also collected here. The specimens consist of pseudomorphous material massive black hematite (red streak) and limonite (bro\\n streak) associated with massive quartz. In the cavities are numerous crystals which reach a maximum diameter of half a centimeter. These crystals are cubes, with occasionally small faces of the octahedron replacing the comers.

Cassiterite.

Cassiterite is not a rare mineral of pegmatites in general, but in the California field it is exceedingly scarce. The following are the only authentic occurrences of

cassiterite in the gem tourmaline pegmatites of southern California of which I know. A specimen showing several small black crystals a few millimeters thick, found in the Himalaya mine, at Mesa Grande, is in the AF. Holden collection at Harvard. Qualitative tests made on a fragment of cassiterite from this specimen conclusively proved the identity of the mineral. Cassiterite is also mentioned by Penfield and Ford as a great rarity associated \\ith stibiotantalite from this mine. In particular they mention a minute octahedron of cassiterite attached to one of their crystals. (Figure x of Penfield and Ford and reproduced in figure x on page). Sterrett mentions an association of cassiterite with pink tourmaline from this mine. The mineral was also identified by the writer on a small group of topaz crystals from the Little Three mine, at Ramona. The specimen was seen in the collection of Mr. W. Maucher of Munich, Germany.

Spinel.

In his enumeration of the minerals from the pegmatite veins at Rincon, Rogers[83] mentions the presence of spinel and describes it as follows:

"The iron-bearing spinel, pleonaste, is found in two of the veins at Rincon is small (0.25 millimeter) crystals associated with small garnet crystals. A few imperfect octahedra were isolated. In fragments the mineral is perfectly isotropic, deep green in color, and its index of refraction is greater than that of methylene iodide, which distinguishes it from other varieties of spinel. Blue spinel has been reported from Rincon but was not found by the writer."

Similar green spinel was observed in the garnet banded rock forming the lower part of the pegmatites on Hiriart Hill. The occurrence of blue spinel is reported by Kunz[84] who writes: Crystals of blue spinel, of about the same size (3 millimeters in diameter), clear, end of good color, have lately been obtained sparingly from the Mack mine, near Rincon, San Diego County.

Quartz.

Occurrence.

Quartz being an essential mineral of pegmatite it follows that an enumeration of the localities of quartz would be a list of the occurrences of pegmatite. The quartz outside of the middle part of the pegmatite dikes presents no points of special mineralogical interest. That of the middle part wherein is found the pay shoot contains well-developed quartz crystals, which present several points of interest. The associations of quartz with the other minerals-particularly tourmaline, feldspar, and mica-are such as to suggest several different orders of succession for the quartz with its associates. Numerous specimens strongly suggest that the formation of the quartz crystals is contemporaneous with that of its associates, other specimens just as strongly suggest an earlier or a later stage of formation for the quartz.

Several specimens have been found notably at the Himalaya mine, at Mesa Grande whereon quartz crystals were pierced by large rubellite crystals, which emerged

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[83] Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego County, California. School of Mines Quarterly.

[84] Kunz, G. P., Gems, jewelers' materials, and ornamental stones of California: California State mining Bureau Bull. No. 37, p. 48, 1905.

on both sides of the quartz. It is most plausible to regard the rubellite crystal as having been completely formed before the quartz reached its final growth. Otherwise the rubellites would have a greater diameter at the free extremities than in the portion embedded in the quartz crystal; whereas the diameter of the entire rubellite crystal is uniform throughout. Similar specimens show quartz crystals containing numerous small greenish-black tourmalines, some of them entirely embedded in the quartz and others projecting slightly from the surfaces. On all such specimens the quartz continued growing after the growth of the enclosed tourmalines had ceased.

Some quartz from the Pala Chief mine shows clearly two distinct epochs in the growth of the crystals. The central portion o the homogeneous and single crystals is pure, transparent, vitreous quartz, whereas the outer portion is an 8-millimeter thick shell of granular-looking quartz filled with radiating needles of pink to white tourmaline. The contact of the two parts is very sharp. The relationship of the two parts is such as to suggest that the formation of the tourmaline crystals caused the cessation of the growth of the quartz crystal. The outer pink shell is always much thinner than the inner clear portion of the crystal. The relations are shown in figure 38.

Figure 38. Quartz crystal with inclusions of rubellite, showing two periods in the growth of the quartz.

In many other specimens, the outside layer of the quartz crystal is penetrated from several millimeters by a large number of crystals of either tourmaline, albite, or lepidolite, which are in small part completely embedded in the quartz but to a very large extent only a small portion of each crystal is inserted in the quartz, the remainder projecting freely into space. Such an association would seem to indicate that the quartz crystal had grown to considerable size before a second mineral became entangled in the same solidification process. In some specimens it seems to be an indication of the saturation point of the second mineral having been reached, whereas in others it may have been the sudden addition of other material that made conditions favorable for the formation of the second mineral. Whatever may have been the cause of the formation of the second mineral, it apparently had a detrimental effect on the continuation of the growth of the quartz, for this ceased rather abruptly. The process continued just long enough to hold most of the crystals of the second mineral firmly to the single much larger quartz crystal.

On many other specimens, crystals of other minerals are firmly attached to the quartz but only imperfectly embedded therein, so that when they are removed only a faint scar is visible on the quartz crystal.

The relationships described show that there was no definite succession of growth of quartz with reference to its associated minerals, but that its formation continued during the entire period of crystallization of the middle part of the pegmatite. It can be stated, however, that in many crystals the quartz continued to grow after the tourmalines and micas had ceased their growth. This does not necessarily imply that there was one continuous epoch in which quartz was continuously being produced; there may well have been several distinct generations. In fact the associations observed on several specimens strongly indicate the existence of more than one more or less distinct generation of quartz crystals.

The massive quartz of the middle part has the same relation to the accompanying minerals as it has in the lower banded part of the pegmatites, namely, that it was the last mineral to form and that it accommodated itself to the already existing minerals and filled in the vacant spaces to form a compact rock free from

cavities or crevices. This phase of the middle part in which gem minerals are frequently found comprises the variety described on page x.

The quartz found in the middle part of the pegmatite is both massive (Pl. VIII A, p.) and also in distinct crystals. The massive phase occurs either as small masses of nearly white quartz, practically pure, or as the allotriomorphic matrix of the tourmalines, micas, etc., which have earlier separated out. There are also to be found large bodies of massive quartz generally of a characteristic gray color, they are especially prominent in the Stewart mine, at Pala. Thin sections show this massive gray quartz to be crowded with minute inclusions and irregular cracks.

The crystals of quartz are colorless, rarely yellowish, smoky (abundant), and of various colors, green, pink, or black, the color being due to included tourmaline needles. They range in size from microscopic crystals to those a foot in length and weighing many pounds.

Crystallography.

The quartz of the middle part is low-temperature quartz, belong to the trapezohedral class. Simple crystals showing only m, r, and z, are abundant, though generally complex interpenetrative twinning can be readily detected. On a majority of the crystals trapezohedral faces are well developed, both left and right handed crystals occurring abundantly. Similar crystals have been described by Waring[85] 80 who gives the forms: m{1010}, r{1011}, x{4151}, t{4041} with the combination as shown in figure 39.

Figure 39. Quartz crystal from Pala after Waring Forms:

The trapezohedron faces vary in size on different crystals from minute faces hardly visible without a lens to those nearly as large as the faces of the prism, as shown in figure 40.

Figure 40. Quartz crystal with large development of the trapezohedron.

The smoky quartz crystals are especially prone to show well-developed trapezohedrons with narrow rhombohedrons between the prism and the unit rhombohedrons.

From a purely crystallographical point of view the quartz crystals from these localities are not especially interesting. A specimen from Ramona has a matrix of albite, with a few spessartite, muscovite, and quartz crystals. These latter are especially rich in forms and the measurement of four crystals has yielded the following results. The dominant forms are the prism and unit rhombohedra with which are associated many other rhombohedra and trapezohedra, a total of 28 forms having been determined.

The p measurements of the unit rhombohedrons which gave good reflections are as follows: 51°47', 52', 52', 48', 56', 51' 53', 51', 45', 51', 54'; average, 51°,51', calculated, 51°47'. The other measurements are as follows:

Occurrence and measurement of forms on quartz.

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[85] Waring, G. A., Quartz crystals from San Diego County. Am. Jour. Sci., 4th series. vol. , p. 1905

Small line faces of s{1121} are present in all three crystals. The measurements of the poor reflections gave extreme values for of 65°13' and 66°01' (calculated 65° 33').

The form {9.2.11.2} lay accurately in the zone of trapezohedra from m{1010}, on crystal No.1 as a narrow face with equal sized faces of {4151} and {5161} and on crystal No.2 with only {5161}. On crystal No. 3 the narrow faces were associates with only {4151} in one case, in the other cases it was the only face between m and s.

The form {F12.11.23.12} was noted only once as a minute line face between {1121} and {3253}, with which forms it lay in a well-defined zone.

The form {16.2.18.7} is represented by a minute face between {5161} and {0111}.

The form {16.4.20.3} lay on the other size of {5161} nearest the neighboring prism m.

Distortions of the crystals are not uncommon, and some flattened parallel to either a prism or a rhombohedron face have been observed. Several crystals have a cubical appearance, awing to the distortion of one set of rhombohedrons. All the distorted forms have often been noted previously and therefore merit no further description.

Opal.

Rogers[86] describes the hyalite variety of opal from Rincon in the following words: "Hyalite occurs as a secondary mineral, forming a thin coating on some of the quartz crystals and albite crystals. It is glassy, transparent with botryoidal surface, and is very brittle. In fragments the hyalite shows very weak double refraction, and some of them give an imperfect spherulitic black cross, which means that the brittle character is due to strain." Kunz quotes F.M. Sickler as reporting hyalite from the upper part of the pegmatites on Hiriart Hill. The writer has not encountered the mineral on any of the specimens examined.

Hematite.

The red oxide of iron was noted only as an alteration product of pyrite. The crystals of pyrite, now altered to pseudomorphous hematite, have already been described. Red iron oxide stains are common throughout many parts of the pegmatite and are largely caused by the alteration of the ferromagnesian minerals of the gabbro. Fairbanks included hematite in his list of minerals found at Pala in 1893.

Limonite.

The brown oxide of iron accompanies the red hematite as an alteration of pyrite. It presents no point of special interest. The many minerals covered with a brown stain owe their apparent coloring to limonite, which, in an impure form, is very abundant, and, like the hematite, results from the alteration of the gabbro.

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[86] Rogers, A.F., Mineral from the pegmatite veins of Rincon, San Diego County, California: School of Mines Quart., vol. 31, p. 208, 1910.

Manganite.

The black manganese oxide, manganite, is a secondary mineral resulting from the alteration of primary manganese-bearing minerals of the pegmatite. The most abundant of these primary minerals is garnet, especially that from the lower banded part of the pegmatite. Analysis shows that these garnets contain about 20 per cent of MnO. By the decomposition of these garnets, black manganite is formed in quantity and colors the entire rock black. Manganite also forms from the alteration of minerals which contain only small quantities of manganese, such as pink tourmaline and spodumene.

The most interesting form of manganite is that of a pseudomorph after lithiophilite, for as shown later, manganite is one of the last products of the long series of alterations through which the crystals of lithiophilite have passed. It is found in the Stewart mine, at Pala, forming either an outside shell or else forming nearly the entire mass of what was originally lithiophilite. The crystals of lithiophilite shown in Plate x consist now essentially of manganite. Its stage in the alteration cycle is well shown by Plate   It also forms by the alteration of triplite. It is identified by its color, streak, and hardness, and by its chemical composition, consisting essentially of manganese oxide and water.

Psilomelane.

Psilomelane with the same qualitative composition as manganite is distinguished there from by its hardness and luster. It was observed as minute veins in the manganite resulting from the alteration of lithiophilite.

Fluorite.

Fluorite has been identified only in the Himalaya mine, at Mesa Grande. Mr. E. Schernikow has supplied the Survey with material on which the following short description is based. The small piece of fluorite shows only cleavage faces and has a peculiar brown color similar to that possessed by the apatite found with it. The fluorite has a good octahedral cleavage and the crushed fragments are isotropic. Its density is 3.18. No analysis was made of the material, but qualitative tests definitely proved the mineral to be fluorite.

Microlite

The presence of microlite from San Diego County (probably from the Himalaya mine, at Mesa Grande) was determined by Rogers.[87] The honey-yellow mineral was associated with albite, lepidolite, tourmaline, and colorless apatite. The octahedral crystals showed narrow faces of d{11 0} and n{311 }. Several yellowish-brown crystals from Hiriart Hill are probably likewise microlite. They are small, several millimeters thick, and showed the octahedron truncated by small faces of the cube.

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[87] Rogers, A.F., Notes on rare minerals from California; School of Mines Quarterly., vol. 33, p. 375, 1912

Hatchettolite

Occurrence

Hatchettolite is a very rare mineral found in the mica mines of Mitchell County, N. C. and in Madagascar. Chemically, the essential components are Ta2O5, Cb2O5, VO3, and CaO, with small quantities of other constituents. It is isometric, in octahedrons similar to pyrochlore and microlite.

The mineral has been observed on several specimens from the Himalaya mine, at Mesa Grande. It occurs in small crystals, scarcely over a millimeter thick, embedded in pink tourmaline and in quartz crystals. Three such crystals are shown in the colored plate forming the frontispiece.   They are on the right side of the large quartz crystals. Several other crystals are present on this specimen both in the quartz and the tourmaline.   Professor Palache was kind enough to send the writer several tourmalines containing embedded crystals of this mineral. One of these is shown enlarged in Plate XXV A and is described below under the heading of alteration. What is probably the same mineral was noted by Rogers,[88] though he refers to the specimen investigated to pyrochlore.   As however, his material gave a uranium test, it is more likely to be hatchettolite.

Crystallography.

The crystals are isotropic under the microscope, agreeing with their outward isometric form. One of the crystals on the large group shown in the frontispiece is a simple dodecahedron. Professor Palache measured a minute crystal which he extracted from tourmaline and which showed brilliant faces. This crystal had never before been exposed to the air. The forms present are the cube, octahedron, dodecahedron, the trapezohedron {353}, the trisoctahedron {377} and the form {052}. The following are the measured angles obtained by Professor Palache.

Measured angles, hatchettolite, Mesa Grande, California
[Measured by Prof. Palache.]

Form	Measured		Calculated.	
	φ	ρ	φ	ρ
d{110}	0°01'	45°07'	0°00'	45°00'
d{110}	90°00'	45°15'	90°00'	45°00'
d{110}	90°00'	45°20'	90°00'	45°00'
o{111}	44°50'	54°47'	45°00'	54°44'
o{111}	44°40'	55°00'	45°00'	54°44'
o{111}	45°15'	54°47'	45°00'	54°44'
{052}	91 °15'	68°45'	90°00'	68°12'
{353}	31°14'	62°36'		
{377}	23°14'	47°47'		

Alteration

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[88] Rogers, A.F., Notes on rare minerals from California: School of Mines Quar., vol. 33, p. 375, 1912.

The alteration of hatchettolite has yielded some interesting results, and in fact the determination of this mineral as hatchettolite is partly based on the effects produced by its alteration. It was noticed that the host of the minute crystals was at all places cracked and at several places discolored. In the specimen reproduced in the colored frontispiece the quartz surrounding the hatchettolite crystals is cracked and in part split off. The same is true of tourmaline where that mineral is the host. The tourmaline crystal shown in Plate XXV A, which contains a crystal of hatchettolite partially embedded in it, is likewise traversed by a series of cracks radiating from the central enclosed crystal. The central portion of this tourmaline is much darker red than the remaining portion. The cavity in which the hatchettolite reposes has a decided hexagonal shape due to the dodecahedral shape of the original crystal. The present mass of enclosed mineral is irregular in outline and bounded by indefinite rounded surfaces. It presents all the appearances of being a residual part of a former crystal which occupied the entire cavity.

These phenomenon are shown in Plate XXV A, which is a reproduction of the specimen enlarged fourfold. They are also shown diagrammatically in figure 41 which serves to explain the illustration of Plate

Figure 41. Tourmaline crystal enclosing crystal of hatchettolite, Himalaya mine, Mesa Grande. Enlarged four times. Shows series of cracks in tourmaline, central core of dark red tourmaline, dodecahedral (hexagonal in section) outline of cavity, and present residual mass of hatchettolite.

The cracking of the tourmaline and quartz hosts was caused by the increase in volume due to the alteration and hydration of the hatchettolite. Prof. Palache noticed that the crystals of hatchettolite rapidly became opaque and crumbled to a powder where they were exposed to the air. The presence of uranium (and radium?) in the hatchettolite may have caused the surrounding tourmaline to become darker colored. The quantity of material is so small that the investigation cannot be extended further. The few results available, however, indicate a very interesting state of conditions resulting from the alteration of a uranium mineral.

Columbite Group

Nomenclature

The name columbite has been used as a species name and also as a group name. As a species it has most generally been used to designate that orthorhombic mixture of iron and manganese columbates and tantalates in which iron and columbium predominate. In opposition to tantalite, the name has also been applied to those mixtures in which the columbium predominates over the tantalum irrespective of the relative amounts of iron and manganese present. The group name naturally applies to all the various mixtures of these minerals as they are found in nature.

In order to more definitely characterize. certain occurrences and to place the nomenclature on a more systematic basis the following scheme of nomenclature is used in this report. The name columbite is used as a group name, analogous to garnet, tourmaline, and feldspar. It covers any one of the following definite mineral species as well as any mixture of two or more of these species.

Manganocolumbite MnO·Cb20s

Ferrocolumbite	FeO·Cb20s
Manganotantalite	MnOTa205
Ferrotantalite	FeOTa20s
Stibiocolumbite	Sb203·Cb20s
Stibiotantalite	Sb203Ta20

All six of these species have been found in nature in a nearly pure state and the names have already been used in the literature to a considerable extent.

The first two species may be readily distinguished from the next two by their lesser density. As iron and manganese have nearly the same atomic weight, the densities of manganocolumbite and of ferrocolumbite are nearly identical. As soon as any tantalum replaces the columbium in either of these two species, the density becomes appreciably grater. The lowest authentic recorded density of columbite is 5.26, and the highest value for tantalite is 7.30. On the basis of these values, such mixtures as having a density below the mean of the two values given, namely 6.28, belong to the columbium part of the group; those having a higher density than 6.28 belong to the tantalum part of the group. The relative abundance of iron and manganese has to be determined chemically, although generally the manganese rich members are translucent and have a reddish color whereas the iron rich members are opaque and black.

The diagnostic properties on which the specific classification is to be made is then as follows:

Columbite group (Orthorhombic).

Antimony absent:[89]

| Density less than 6.28 | Manganese predominates over iron = manganocolumbite
Iron predominates over manganese = ferrocolumbite. |
| Density greater than 6.28 | Manganese predominates over iron = manganotantalite Iron predominates over manganese = ferrotantalite |

Antimony present:

| Density less than 6.6 | stibiocolumbite |
| Density greater than 6.6 | stibiotantalite |

The chief diagnostic properties of the six species of the columbite group, as given, are summarized in the following table which will serve as a means of distinguishing them. The data have been taken from the literature and from the descriptions of the California minerals, as given in the following pages.

DID NOT TYPE MANUSCRIPT TABLE

Crystallographic orientation.

The crystals of the antimony-free species of the colurnbite group

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[89] The test for antimony can be made very easily as follows: Dissolve the powdered mineral in HF, and add hydrogen sulphide filler. If the mineral was either stibiotantalite or stibiocolumbite, precipitated red antimony sulphide will show very plainly.

(manganocolumbite, manganotantalite, ferrocolumbite, ferrotantalite) are very similar in their combinations and angular values. They are therefore best considered together in discussing the relative merits of the orientations proposed. Several orientations have been put forward by different authors but only two have acquired any prominence. These are the positions taken by Schrauf and by Dana, respectively. These two positions are as follows:[90]

Dana.   Schrauf.
a axis = 0.8285   a axis = 0.4023

c axis = 0.8898   c axis = 0.3580

Cleavage face = (100)   Cleavage face =(101)

The two orientations yield two series of indices for the forms, and in accordance with modern usage that orientation is to be preferred which, other things being equal, yields the simplest indices. The various combinations described in the literature for the members[91] of the columbite group have been compiled and the percentage occurrence of the forms present in at least 20 per cent of the combinations is as follows:

Percentage of occurrence of principal forms of columbite.

Forms	Percentages	Symbol according to Schrauf	Symbol according to Dana
a	92	010	100
u	88	111	133
g	88	110	130
b	85	100	010
m	84	130	110
c	70	001	001
e	48	201	021
n	46	211	163
k	40	011	103
o	33	131	111
z	28	150	530
l	27	012	106
β	20	121	233
s	20	221	263

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[90] The angular constants obtained by Dana are accepted as being the most accurate. Brögger (Die Mineralien d. siidnorw. Granit pegmatitegänge. Videnskabs-Selskabets Skrifter, Math.-naturw. Klasse, I, 1906, no. 6, p. 60) has recently calculated a new axial ratio which is very close to the one given by Dana. His fundamental angles are as follows, the symbols being given in Schrauf's orientation: (111): (111) = 29°55' (according to Dana 2 57'); (111): (111) = 80°09' (according to Dana, 7 54'). The axial elements calculated by Brögger (Schrauf's orientation) are: *a; b; c* = 0.40093 :1: 0.35867.

[91] No attempt was made to differentiate the forms for the separate species, such as manganocolumbite, etc.

The indices of the forms are so much simpler in Schrauf's orientation than in that of Dana, that the position of Schrauf is clearly to be preferred. It is accordingly adopted in this report. An analogous orientation is shown to be most rational for stibiotantalite (p.).

Manganotantalite.

Occurrence

Manganotantalite, essentially MnO.Ta2O5, has been found at Pala in well-developed and large crystals. The best specimen (shown in Plate XXV, B) was found in the Katerina mine on Hiriart Hill and was generously presented to the Geological Survey for study and future preservation in the United States National Museum at Washington, D.C., by Messrs. M.M. Sickler and B. Hiriart. Several smaller pieces were also obtained by Mr. John Reed in one of the prospects on Pala Chief Hill. Several large pieces were found in the Esmeralda mine and presented for study by Mr. H. C. Gordon. A single specimen was obtained from the Himalaya mine, at Mesa Grande, and was kindly donated by Mr. E. Schernikow.

The columbates and tantalates of the California pegmatites are found only in the pay shoots of the middle part. The large crystal of manganotantalite from the Katerina mine is bounded on one side by massive quartz and on the other side by platy albite. The back of the crystal and of the whole specimen seems to have laid against a large spodumene crystal which measured at least 7 by 6 inches across. Below the crystal of manganotantalite occurs about 4 inches of the same mineral in a massive cleavable form. The specimens from Pala Chief Hill are attached to albite. ·(See fig. 43.)

PLATE XXV. A, hatchettolite; B, manganotantalite; C, D, E, stibiotantalite; F, G, H, apatite.

Plate XXV. Hatchettolite, manganotantalite, stibiotantalite, and apatite.

A. Hatchettolite, embedded in rubellite, Himalaya mine, Mesa Grande. Enlarged 4 times. The hatchettolite is altered and has lost about half of its material. The hexagonal shape of the cavity in which it reposes suggests an original dodecahedral crystal. The rubellite is traversed by a set of radiating cracks caused by the increase of volume of the hatchettolite which attended the beginning of its alteration. An aureole of deep red surrounds the cavity and a relation to a radioactive effect produced by the uranium present is suggested. The relations are diagrammatically sketched in figure 41, page x. The specimen in the Mineralogical Museum of Harvard University, was kindly loaned to the Survey by Prof. Charles Palache. Described on page y.

B. Manganotantalite, Katerina mine, Hiriart Hill, Pala. Natural size. The interpretation of the crystal is shown in figure 42 on page   . Some of the smaller crystals (in the center of the photograph) are deep red in color and translucent. The excellent cleavage (b {010}, Schrauf's orientation) is very well shown in the photograph. The specimen was kindly presented to the Survey by Messrs. M.M. Sickler and B. Hiriart and is now in the United States National Museum. Described on page

C. Stibiotantalite from the Himalaya mine, Mesa Grande. Natural size. The rectangular crystal is the largest one known and is now in the Mineralogical Museum of Harvard University (the A.F. Holden collection). Described on page

D. Tabular crystal of stibiotantalite from the Himalaya mine, Mesa Grande.

Natural size. In the collection of the American Museum of Natural History in New York City. Described on page

E. Group of stibiotantalite crystals on feldspar, Himalaya mine, Mesa Grande. Natural size. In the Mineralogical Museum of Harvard University (the A.F. Holden collection). Described on page

F. Apatite from the San Diego mine, Mesa Grande. Natural size. Note the prominent horizontal markings. Now in the United States National Museum. Described on page x.

G. Apatite, prismatic habit, Himalaya mine, Mesa Grande. Natural size. In the Mineralogical Museum of Harvard University (the A.F. Holden collection). Described on page z.

H. Apatite with rubellite, tabular habit, Himalaya mine, Mesa Grande. Natural size. Note the peculiar canal-like markings. Kindly loaned the Survey by Mr. E. Schernikow, of New York City.

Crystallography.

The crystals are simple in their combinations. The large crystal on the specimen from the Katerina mine shown in Plate shows the forms: b{010}, a{100}, k{011}, n{211}, u{111}, z{150}, g{130}, given in the order of their relative size. The habit of the crystal is shown in figure 42.

Figure 42 Manganotantalite from the Katerina mine, Hiriart Hill, Pala. Forms: b{010}, a{100}, z{150}, g{130}, k{011},u{111}, n{211}. A second crystal, very similar in appearance to the one figured, showed, in addition to the forms listed, small faces of l {101} and e {201}.

Physical properties.

Cleavage parallel to the brachypinacoid b {010} (Schrauf's orientation) is well developed in manganotantalite and plates bounded by plane and brilliant surfaces are easily obtained. The large crystal from the Katerina mine, illustrated in Plate XXV B., shows the cleavage lines well developed. The second very imperfect cleavage normal to b{010} and parallel to a{100} was recognized only under the microscope. Many of the brachypinacoidal cleavage surfaces, especially of the manganotantalite from Pala Chief Hill, though bright and smooth, are curved (fig. 43). The surfaces on some of the specimens suggest the curved cleavage surfaces of stibnite. The hardness of the mineral is 4.5, much lower than that of the black iron columbites. Apatite will readily scratch manganotantalite, which leaves only a brown trail on apatite but does not scratch it.

Figure 43 Curved cleavage surface of manganotantalite from Pala Chief Hill.

The density of the dark-red fragments which w re analyzed was determined by a pycnometer to be 6.51. Correcting this value for the 4 percent admixed quartz and albite (density 2.6), the true value is found to be 6.67. The mineral from the Esmeralda mine has a density of 7.0.

Piezoelectric effects were looked for on the transparent manganotantalite from the Katerina mine, but none were observed. The procedure followed was that described by Penfield and Ford (see p.   ) and used by them on stibiotantalite.

Optical properties.

The color is a dark reddish-brown, becoming black in places. Where piece is fairly translucent, the color is a deep red. Various shades of red and yellow are also shown by pieces sufficiently clear to transmitted light. The luster is decidedly resinous and submetallic.

The streak is a light buff varying slightly for the different specimens. The Cream Buff and Chamois on Plate XXX of Ridgway's Standard Colors define the streak more accurately. In the large specimens the material is opaque. Selected pieces, however, are translucent for a thickness of nearly 3 millimeters; transparent pieces 1 millimeter thick are not difficult to obtain.

The transmitted colors range from a deep red-orange for the thickest pieces, through orange, to pale yellow for the thinnest pieces. The optical orientation is as follows. The axial plane is a{100} (Schrauf's orientation), the acute positive bisectrix is normal to c{001}. Therefore a-axis = Y, b-axis = X, and c-axis = Z. The refractive indices were measured by Esper S. Larsen for lithium light: a = 2.22, {3 = 2.25, 'Y = 2.29. Optically positive, 2V large, dispersion strong, r > v. Pleochroism is not noticeable in think cleavage plates; in thicker fragments, the direction parallel to the c-axis (Z) is a red- orange whereas normal thereto (Y) the color is more of a yellow-orange.

Chemical composition.

An analysis was made of a small quantity of selected, transparent, red manganotantalite from the Katerina mine. Columbium and tantalum oxides were not separated but the density (6.51) of the mineral shows that tantalic oxide is present in large quantity. The small quantity of adhering quartz and albite could not well be directly determined and is therefore given by difference. The essential point in the analysis is the relative quantity of iron and manganese, the latter being greatly in excess.

Analysis of manganotantalite,
Katerina mine, Pala, California.
W.T. Schaller, analyst.

$(Cb,Ta)_2O_5$	79.39	
FeO	1.72	
MnO	14.87	
Quartz, feldspar	4.02	(by difference).
	100.00	

Heated before the blowpipe flame, the mineral fuses slightly and becomes more yellowish in color. The powdered mineral if finely powdered dissolves slowly in HF. Duparc[92] described a columbite from Madagascar (containing Nb2O5, 63.77 per cent; Ta2O5, 11.33 per cent; FeO, 11.38 per cent; MnO, 8.79; U3O2, 2.02 per cent;

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[92] Duparc, L., Sabot, R, and Wunder, W., Contribution a l'etude des mineraux des pegmatites de Madagascar: Bull. soc. franc., mineralogic, vol. 36, p. 13, 1913.

miscellaneous, 2.35 per cent; total, 99.64) which is completely soluble in HF.

Ferrotantalite.

Localities.

Ferrotantalite, essentially $FeO \bullet Ta_2O_5$, has been found at Rincon, where several crystals have been obtained from both the Mack and the Victor mines. A crystal from Ramona was described by Eakle and a small specimen, showing no distinct crystals, was found in the Fano mine, at Coahuila in Riverside County.

Crystallography.

A crystal from the Little Three mine, at Ramona, was described by Eakle[93] as short prismatic in habit, about 2 centimeters thick. Thirty-six faces are present belonging to the forms: a{100}, {010}, m{110}, g{130}, z{150}, y{160}, e{021}, u{111}, s{221}, n(211), {121}, o{l31}, r{l41}. The last named form, r, was not observed before on columbite. Eakle's drawing representing the crystal is reproduced in figure 44.

Figure 44 Ferrotantalite, Ramona. (After Eakle). Forms: a{100}, b{010}, m{110}, g{130}, z{150}, y{160}, /{021}, u{111}, s{221}, n{221}, {121}, o{131}, r{141}.

A crystal from the Mack mine, at Rincon, showed the combination: b{010}, a{100}, c{001}, Z{150}, g{130}, m{110}, h{021}, f{032}, k{011}, 1{012}, e{201}, u{111}, n{211}, s(221}. The crystal, shown in figure 45, measured 28 (a axis) by 10 (b axis) by 27 millimeters (c axis). Its density is 6.47. A smaller crystal showed the combination: b{010}, a{100}, c{001l},{121} as shown in figure 46.

Figure 45 Ferrotantalite from the Mack mine, Rincon. Forms: b{010}, a{100}, c{001}, g{130}, m{110}, h{021}, f{032}, k{011}, /{012}, e{201}, u{111}, n{211}, s{221}.

Figure 46 Ferrotantalite from the Mack mine, Rincon. Forms: b{010}, a{100}, c{001}, {121}.

Physical properties.

No distinct cleavage was seen on any of the ferrotantalite from California. The fracture is irregular, the broken surfaces having a hackly appearance. The hardness is 6. The color is black, and the luster bright metallic. The streak is a dark brown, the different crystals yielding streaks comparable to liver brown, Carob brown, or Chestnut brown (Pl. XIV of Ridgway's Color Standard). No columbite from California gave a black streak.

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[93] The mineral is tentatively placed under ferrotantalite, although its properties were not sufficiently determined to make its assignment to ferrotantalite an absolute one.

Stibiocolumbite.

Nomenclature.

In their description of stibiotantalite from California, Penfield and Ford give an analysis of a crystal in which the columbium greatly predominates over the tantalum both in weight and in molecular percentages. Their analysis, as later corrected by Ford[94] is reproduced here with the ratios calculated there from.

Analysis and ratios of stibiocolumbite (given as stibiotantalite), Mesa Grande. [Penfield and Ford, analysts.]

Composition

The analysis shows the mineral analyzed to consist of a mixture corresponding to 78.4 per cent of antimony columbate and 21.6 per cent of antimony tantalate. As they columbate overwhelmingly predominates, the specimen is essentially an antimony columbate for which the name "stibiocolumbite" is proposed. In strict terminology the particular specimen analyzed is a tantalic stibiocolumbite.

General properties.

An attempt was made to correlate the changes in some of the physical properties of stibiocolumbite and stibiotantalite with the corresponding change in chemical composition, but the published data are not sufficiently concordant to yield reliable results. This can be shown by comparing the densities given with the chemical composition.

Comparison of densities with chemical composition, stibiocolumbite and stibiotantalite, stibiocolumbite and stibiotantalite.

DID NOT TYPE MANUSCRIPT TABLE.

The chemical composition of the last two samples of stibiotantalite are very similar, as shown by the nearly identical percentages of Nb_2O_5 + Ta_2O_5 and the Sb_2O_3, yet the densities given are widely apart.

By using the available results as far as possible an approximate determination of the density of pure stibiocolumbite ($Sb_2O_3 \cdot Nb_2O_5$) as 5.6 was obtained. Penfield and Ford calculated 5.73. a density of approximately 6.6 represents a mixture of equal molecular parts of stibiocolumbite and stibiotantalite. The density of pure stibiotantalite was calculated by Penfield and Ford to be about 7.90.

The criterion for separating these two species, based on their density, is then as follows: If the density is below 6.6, the mineral is stibiocolumbite; if the density is higher than 6.6, the mineral is stibiotantalite.

The crystals described crystallographically by Penfield and Ford were not differentiated by their density and it is therefore not possible to say whether any of

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[94] Ford, W.E., Mineral notes from the mineralogical laboratory of the Sheffield Scientific School. I. Note on some analyses of stibiotantalite: Am. Jour. Sci., 4th ser., Vol. p. 19

them belong to stibiocolumbite. As the majority of the crystals studied by them have a density higher than 6.6, it is safe to refer them all to stibiotantalite. The crystals of stibiocolumbite are without question very similar in combination and angular values to those of stibiotantalite, just as those of manganocolumbite and manganotantalite are very similar.

Penfield and Ford give the optical constants of two crystals; one of them having a density of 6.299 is stibiocolumbite. The mineral is orthorhombic, and the axial plane is parallel to b{010} (Schrauf's orientation). The acute bisectrix is normal to c{001}. Therefore a axis = X, b axis = Y, c axis = Z. The optical constants determined by Penfield and Ford are:

Optical constants of stibiocolumbite.

Light	Refractive indices.			Birefringence	Axial angle.
		β	γ	$(\gamma - \beta)$	2V calculated.
lithium	2.3686	2.3876	2.4280	.0594	70°00'
sodium	2.3977	2.4190	2.4588	.0611	73°25'
thallium	2.4261	2.4508	2.4903	.0642	77°50'
sodium	2Ha (measured) = 113°11', therefore 2V = 72°37'.				

In its other properties, such as color, luster, and cleavage stibiocolumbite doubtless is similar to stibiotantalite.

Stibiotantalite.

Localities.

Stibiotantalite was first found in West Australia and a description of it was published by Goyder[95] in 1892 and 1893. It was found in massive rounded water-worn fragments in sand. The mineral was later found (about 1901) in beautiful crystals in the Himalaya mine, at Mesa Grande, and in 1906 a model description of it from this new occurrence was published by Penfield and Ford. Some minute crystals from Ramona were then identified by the writer as stibiotantalite. These crystals are too minute for a determination of their density and the quantity of material is much too small for any chemical investigation. It could not be determined whether these Ramona crystals are stibiocolumbite or stibiotantalite, but they are regarded as stibiotantalite because at Mesa Grande it is so much more abundant then stibiocolumbite. In 1909 Ungemach gave a description of some stibiotantalite crystals from Mesa Grande, noting a number of new forms.

The paper by Penfield and Ford is so complete and thorough that there remains little if anything to add to their description of the Mesa Grande material. The

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[95] Goyder, GA., Stibiotantalite: a new mineral: Proc. Chem. Soc., vol. 9, p. 184, 1893; Jour. Chem. Soc., vol. 63, p. 1076, 1893.

properties of the mineral as given in this report are therefore abstracted from the paper of Penfield and Ford. Some of their conclusions, however, are of such a nature that they warrant closer study. In particular the orientation given to the crystals is a most unusual one and has already been criticized by Ungemach. It is therefore discussed in some detail.

Stibiotantalite was found as loose crystals and fragments as attached crystals, and also as crystals embedded in the firm rock, associated with the pay shoot minerals of the middle part of the pegmatite-gem tourmaline, pink beryl, quartz, orthoclase, lepidolite, etc. Two of the largest of the loose crystals are shown in Plate XXV, C and D; and a group of small crystals attached to feldspar is shown in Plate XXV, E. At the Little Three mine, at Ramona, the minute crystals are found in the cavities of the cavernous albite (shown in Plate VIII) where they are associated with well-crystallized albite, green tourmaline, lepidolite, and topaz.

Crystallography.

Orientation.

Penfield and Ford endeavored to bring out a close relationship between the crystals of stibiotantalite and those of columbite and in doing so assigned an unnatural position for their mineral and made the indices of stibiotantalite very complex. The only pyramid present, for example, received the symbol {4.12.9}.

The need for giving an unnatural orientation to stibiotantalite is chiefly due to the fact that orientation given to columbite is in itself unnatural. The crystals of stibiotantalite are compared with those of columbite set up in Dana's orientation, which is, as already stated, not the rational one for the mineral. Had the authors adopted Schrauf's orientation for columbite and placed stibiotantalite on the same basis, the relation of the two minerals would have been clearly brought out and the forms of stibiotantalite would not have been so complex. This can be readily shown by a comparison of the two minerals, retaining the symbols proposed by Penfield and Ford but changing them to the orientation of Schrauf.

Comparison of stibiotantalite with columbite according to Schrauf's orientation.

Columbite.	Stibiotantalite
a= 0.4023	a= 0.3997
c = 0.3580	c = 0.3754

Form	Letter	Form
010	b (a, Penfield and Ford) m (g, Penfield and Ford)	010
110	n h	110
023		023
021		021
- - -	w	403
-.-.-.		443

By changing the symbol of the pyramid from (443) to (111), a slight change is made in the value of the c axis. The axial ratios are then not so close as those shown in the table, but the indices of the crystal forms become much simpler and the ratios remain sufficiently close to show the relationship between the two minerals. The modified orientation, as just mentioned, is the one finally adopted for stibiotantalite.

In the orientation given by Penfield and Ford the comparison of the axial ratios is as follows:

Stibiotantalite .... a : b : c = 0.7995: 1 : 0.8448;
Columbite .... a : b : c = 0.8285 : 1 : 0.8897.

The crystals of stibiotantalite can be oriented in another way, which would show a slightly closer agreement in values to columbite (using Dana's orientation) and would give much simpler set of indices for the forms.

The form a{100} (Penfield and Ford) becomes {010}
The form g{130} (Penfield and Ford) becomes {210}
The form n{209} (Penfield and Ford) becomes {014}
 The form h{203} (Penfield and Ford) becomes {045}
The form w{4.12.9} (Penfield and Ford) becomes {212}

The axial ratios are then as follows:
Stibiotantalite .... a : b : c = 0.8339 : 1 : 0.9394;
Columbite .... a : b : c = 0.8285 : 1 : 0.8897.

By this change, the cleavage directions are not the same and the general character of the indices is not satisfactory. The modified Schrauf's orientation is by far the best.

The various orientations given show what a close relationship exists between the angular values of the two minerals and, as again stated later, Penfield and Ford were entirely justified in establishing the fact that stibiotantalite and columbite are very closely related. Ungemach's criticism of this relationship is not considered valid. In criticizing the original orientation of stibiotantalite, Ungemach considered the mineral to be a double oxide ($SbO_3 \cdot Ta_2O_5$)analogous to cervantite ($Sb_2O_3 \cdot SO_5$) and not a salt (($SbO)_2(TaO_3$)) analogous to the formula of the columbite group ($Fe(TaO_3)_2$), for example. A careful consideration of his reasons shows that they can hardly be

considered valid. Moreover, the relationship between the two minerals is a very close one and they naturally fall into the same group of minerals in any systematic classification. The objections raised by Ungemach will be considered here, for the crystallographical orientation of stibiotantalite is dependent on whether or not a close relationship with columbite exists.

It can not be definitely stated, as Ungemach did, that in nature the oxides of antimony always play the part of an acid. Recent interpretations of the composition of certain minerals indicate that many elements may act both as an acid and as a base-even in the same compound. Consider for instance the minerals rutile and cassiterite: these are regarded by Brögger, the writer, and others as having the formulas $(TiO)(TiO_3)$ and $(SnO)(SnO_3)$, respectively. In other words, rutile is titanyl metatitanate; cassiterite is stannyl metastannate. So too, cervantite is more probably a salt, namely antimonyl antimonate $((SbO)(SbO_3))$, than a double oxide. Ungemach's statement that antimonyl can only form salts with strong adds might apply to artificial salts made in the laboratory, but it certainly cannot be made to apply to natural minerals representing an innumerable list of compounds whose stability is different from what may be produced artificially in the laboratory..

Ungemach objects to stibiotantalite and columbite being considered as isomorphous. Yet nowhere in their paper do Penfield and Ford call the two minerals isomorphous. They are most cautious in what they say. Their only references to the relationship of the two minerals are as follows: In habit they resemble columbite, and, as will be shown, the two minerals are related both in chemical composition and axial ratio (p. 62}.

The general resemblance to columbite is shown by the prominent development on both species of the macropinacoid a [the brachypinacoid b in the orientation here adopted}, parallel to which stibiotantalite has a highly perfect and columbite a distinct cleavage, while both minerals have an indistinct cleavage parallel to the brachypinacoid *b* [become the macropinacoid a]. The prism *g* [become m] is always present on stibiotantallte, while on columbite it is seldom wanting and often prominent " (p. 66).

The chemical relation between stibiotantalite and columbite may perhaps be represented best by developed formulas, as follows:
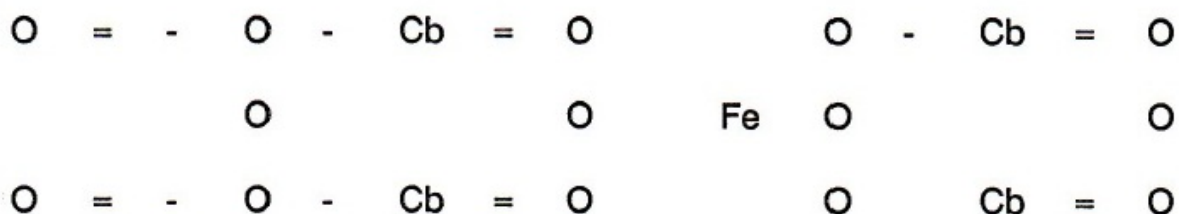
What it is desired especially to bring out by the formulas is that in stibiotantalite two univalent antimonyl radicals (O = Sb) play the same role as a bivalent atom of Fe in columbite, hence, chemically, the mineral is regarded as a basic antimony tantalate, respectively, niobate)p. 74).

It may be that the similarities in habit, cleavage, and axial ratios between stibiotantalite and columbite, as pointed out earlier in this paper, are mere matters of accident, but taken in connection with the chemical formulas, this does not seem at all probable (p. 75). In axial ratio, development and occurrence of several forms, the mineral is related to columbite (p. 77)."

Ungemach's criticism falls to the ground when the quoted statements, in which no mention is made of the two minerals being isomorphous are considered.

Ungemach's statement that columbite has only a poor cleavage is not true, as many columbites give an excellent cleavage. In particular the manganotantalite from Pala, already described, has an excellent cleavage. His statement that most of the stibiotantalite forms do not occur on columbite is also disproved. (See p..)

No valid reason has therefore been brought forward which sustains any objection to considering stibiotantalite and columbite as being closely related. In fact, the relationship is a very close one as has been insisted on in this report and as has been verified by the comparative tables.

It has been shown that the rational orientation for columbite is that of Schrauf, in which the cleavage plane is the brachypinacoid b{010}. If the crystals of stibiotantalite be given a similar orientation, with the cleavage plane as b{010} and the striations thereon placed vertical, then the mineral is so placed as to have simple indices for its forms and shows a fairly close analogy to columbite in its angular values.

Another factor to be considered in giving the best orientation to a crystal is the practical one. A mineral should be so oriented crystallographically that a crystal of it to be measured can be easily and quickly set up correctly on the goniometer. The two-circle goniometer of Goldschmidt is by far the best and most practical one in use today. Measurement of a crystal giving the coordinate angles ϕ and p can be readily interpreted by use of the tables of angles compiled by Goldschmidt. The easiest and most accurate way of adjusting a crystal on the two-circle goniometer in true polar position is by means of a striated prism zone. It is therefore of great practical value to have a complete striated zone on a crystal taken as the prism zone. The orientation for stibiotantalite here proposed retains the striated zone bm as the prism zone. In Ungemach's orientation this zone becomes the macrodome zone.

The new orientation proposed is given below, to which is added that of Penfield and Ford and of Ungemach. Those forms which likewise occur on columbite are also given, and, ad can be readily seen, Ungemach's statement that similar forms do not occur on columbite is not borne out by the facts. The letters for the pinacoids and for two of the prisms have been changed so that

a (Penfield and Ford) = b (Schaller);
m (Penfield and Ford) = g (Schaller);
g (Penfield and Ford) = m (Schaller).

Ungemach did not assign any letters to his few forms: these have therefore been given letters.

Orientations and forms of stibiotantalite.

Letter.	Schaller.	Penfield-Ford.	Ungemach.	Columbite.
(a) b	010	100	001	010
c	001	001	010	001
(g)m	110	130	101	110
(m)g	130	110	103	130
z	150	530	105	150
d	170	730	107	170
j	190	310	109	(290)
l	011	409	011	011
n	012	209	021	012
h	032	203	023	032
	101	043	110	101
w	111	4.12.9	111	111
t	171	28.12.9	117	(161)
s	133	449	133	133
r	132	223	123	- -

The needless complexity of the indices in the orientation of Penfield and Ford is avoided in both the orientation proposed by the \\Titer and in that given by Ungemach. The crystallographical relationship of columbite and stibiotantalite is clearly shown in the proposed orientation whereas no such relationship exists with Ungemach's orientation, as the following comparison shows.

Comparison of columbite with Schaller's and Ungemach's orientation of Stibiotantalite

	Stibiotantalite. (Ungemach)	Columbite.	Stibiotantalite. (Schaller).
a axis	0.8879	0.4023	0.4169
c axis	2.1299	0.3580	0.4696
Cleavage	(001)	(010)	(010)
Prominent	horizontal	vertical	vertical

Moreover the forms of the richest zone of stibiotantalite has no correspondence with columbite for Ungemach's orientation, whereas for the writer's orientation the correspondence is good.

Stibiotantalite	(Ungemach)	(001)	(109)	(107)	(105)	(103)	(101)
Columbite		(001)	--	--	--	--	(101)
Columbite		(010)	--	(170)	(150)	(130)	(110)
Stibiotantalite	(Schaller)	(010)	(190)	(170)	(150)	(130)	(110)

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The angular values of the forms of the prism zone for the two minerals show a close agreement.

Comparison of the angular values of the prisms.

Form.	Columbite.	Stibiotantalite.
190	--- ----	4° 55'
170	19°33' '	18°55'
150	26°26'	25°37'
130	39°38'	38°39'
110	68°05'	67°22'

The orientation proposed has the further advantage over that of Ungemach that the completely striated zone is made the prism zone. A new crystal can therefore be at once correctly and accurately adjusted on the two-circle goniometer for complete measurement Reference to the table on p. xx suffices then for the immediate determination of any of the known forms.

Calculation of elements.

The crystallographic values determined by Penfield and Ford have been retained, as no better measurements were obtained. Their fundamntal angles, in the orientation here adopted, are as follows:

m $\wedge$ m = 110 $\wedge$ 110 = 45° 16'; therefore a = 0.4169
m $\wedge$ w = 110 $\wedge$ 111   = 39° 20'; therefore c = 0.4669

On the Ramona crystals the faces in the prism zone were measured with a fair degree of accuracy and the results obtained are shown in the table below.

Measurement of Ø angle for m{110}, stibiotantalite, from Ramona

Crystal Number	Reflection.	ø
1	good	22° 56'
1	good	22° 33'
1	fair	22° 40'
2	fair	22° 47'
2	fair	22° 39'
3	fair	22° 37'
3	fair	22° 37'

The average value is 22° 41' which is very close to the angle obtained by Penfield and Ford, namely, 22° 38'.

Forms and angles.

The forms and coordinate angles for stibiotantalite are shown in the following table adopting the proposed orientation. The angles are calculated from the constants determined by Penfield and Ford.

Forms and angles for stibiotantalite.

a = 0.4169 c = 0.4696 p. = 1.1267

Number.	Letter.	Symbol	ø	p	Observer	Locality [b]
1	b	010	0° 00'	90°00'	PF. U. S.	MG., R.
2	c	001	90° 00'	--	U.	MG.
3	j	190	14° 55'	90°00'	PF. U.	MG.
4	d	170	18° 55'	90°00'	U.	MG.
5	z	150	25° 38'	90°00'	U.	MG.
6	g	130	38° 39'	90°00'	PF. U.	MG.
7	m	110	67° 22'	90°00'	PF. U. S.	MG., R.
8	n	012	0°00'	13°13'	PF. U. S.	MG., R.
9	k	011	0°00'	25°09'	U.	MG.
10	h	032	0°00'	35°10'	PF. U.	MG.
11		101	90°00'	48° 5'	PF. U.	MG.
12	w	111	6°22'	50°40'	PF. U. S.	MG., R.
13	s	133	38°J9'	31°01'	U.	MG.
14	r	132	38°J9'	42°03'	U.	MG.
15	t	171	18°55'	73°57'	U.	MG.

a PF = Penfield and Ford; U = Ungemach; S = Schaller.
b MG = Mesa Grande; R = Ramona.

Combinations.

The combinations observed on the crystals of stibiotantalite as described by Penfield and Ford, by Ungemach, and as measured by Schaller on crystals from Ramona, are shown below.

Combinations observed on stibiotantalite

Crystal Number	Locality.	Reference.	b{010}	j{190}	g{130}	m{110}	{101}	n{012}	h{032}	w{111}
1	Mesa Grande	P.F., Fig. 2	b	–	–	m	–	n	h	–
2	Mesa Grande	P.F., Fig. 3	b	–	–	m	–	n	h	w
3	Mesa Grande	P.F., Fig. 4	b	j	–	m	–	n	–	–
4	Mesa Grande	P.F., Fig. 10	b	–	–	m	–	n	–	–
5	Mesa Grande	P.F., Fig. 11	b	–	–	m	–	n	–	–
6	Mesa Grande	P.F., Fig. 12	b	–	–	m	–	n	–	–
7	Mesa Grande	P.F., Fig. 13	b	–	–	m	–	n	–	w
8	Mesa Grande	P.F., Fig. 14	b	–	–	m	–	n	–	–w
9	Mesa Grande	P.F., Fig. 15	b	–	g	m	–	n	h	w
10	Mesa Grande	P.F., Fig. 16	(cleav.)	–	–	m		–	–h	w
11	Mesa Grande	U. Cryst. 1	b	–	–	m	–	n	–	–
12	Mesa Grande	U. Cryst. 2	b	–	–	m		n	–	w
13a	Mesa Grande	U. Fig. 1	b	j	g	m		n	h	w
14a	Mesa Grande	U. Fig. 3	b	–	–	m	–	n	h	w
15	Ramona	S.	b	–	–	m	–	n	–	w w
16	Ramona	S.	b	–	–	m	–	n	–	w w
17	Ramona	S.	b	–	–	m	–	n	–h	w w

Notes: a) In addition to the forms listed in the table, crystal No. 13 (Ungemach Crystal 3, Fig. 1) showed the forms: c{001}, d{170}, k{011}, t{171}, s{133}, r{l32}; and crystal No. 14 (Ungemach Crystal 4, Fig. 3) the form z{150}.

A statistical review of the combinations shows the following percentage occurrence of the chief forms:

Percentage occurrence of the chief forms, stibiotantalite.

Form.	Percentage occurrence.
m{110}	100
b{010}	94
n{012}	94
w{111}	65
h{032}	30
{101}	18

The first four of these, namely m, b, n, w, occur on the majority of the crystals and are therefore the ones which should determine the orientation of the minerals so as to yield the simplest indices for them. The indices of these forms, m(110), b(010), n(012), and u(111) are as simple as possible and shows that the orientation adopted is the rational one.

Hemimorphism and twinning.

Stibiotantalite is orthorhombic hemimorphic. Penfield and Ford made the a axis the direction of hemimorphism; Ungemach so oriented his crystals that the vertical axis became the direction of hemimorphism; in the proposed orientation the hemimorphism is in the direction of the b axis. All or nearly all of the crystals are polysynthetic twins whereby the symmetry of the normal group is simulated. The twinning axis is the vertical axis c and the composition face is b{010} (Schaller). Owing to the polysynthetic twinning it is not always possible to decide whether a given form is positive or negative, and the hemimorphic treatment of the forms has therefore not been consistently carried out.

Three of the crystals studied by Penfield and Ford showed a marked hemimorphic development. They are shown in figures 47 and 48.

Figure 47 Stibiotantalite showing hemimorphic development. After Penfield and Ford. Forms: b{010}, m{110}, n{012}, h{032}. The brachypinacoid b is drawn in front.

Figure 48 Stibiotantalite showing hemimorphic development. Orthographic projection. After Penfield and Ford. Forms: b{010}, m{H O}, g{130}, n{012}, h{032}, w{111}. The brachypinacoid b is drawn in front.

They are orientated according to pyroelectric department, the b faces to the front all developing negative electricity on cooling, as tested by the carmine-sulphur-lycopodium mixture suggested by Bürker.[96] The crystal shown by figure 47 has at the top two ridges and a valley, but no reentrant angle at the sides: The two ridges on cooling develop positive, and the valley negative electricity. This crystal is a polysynthetic twin, and may be taken as a type for illustrating the structure of other crystals. The vertical axis is the twinning axis, and the brachy pinacoid b the

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[96] Ann. Phys., 1900, I, 474.

composition face. If it is assumed that a hemimorphic crystal has the prism m(110) and the dome n(012) intersecting the front end of the b-axis only, a lamella in twin position would give a ridge and a valley at the top but also reentrant angles at the sides, which do not occur on the crystal shown in figure 44. It seems therefore necessary to assume that, in addition to m to the front, there is a corresponding m(110) behind, and, as well be shown, also, an n(012) behind. An interspersed twin lamella may then show at the sides of the prism m corresponding in direction with m. The prism lettered m, (fig. 47), is therefore to be regarded as a composite face, composed partly of m and partly of m. At the top of such a crystal there may be a ridge and a valley, provided that in the twin lamella there occurs in connection with m not n sloping to the front but n sloping behind. As a matter of fact, only a few of the crystals show reentrant angles at the top, and the faces of later figures lettered nor n must in reality be regarded as composite, made up partly of n and partly of n.

Figures 47 and 48 both show hemimorphic character by the development of n behind, but this face is in reality composite, composed in part of n in twin position. Figure 48 shows prominent reentrant angles at the sides. None of the other crystals show these so prominently, and as a rule reentrant angles are so small as to give the effect of fine striations parallel to the vertical axis, or a rounding of the obtuse edge between m and m, as if resulting from oscillatory combination, (fig. 48). The crystal represented by figure 48 is the only one showing any prominent development of a replacement of the edges between b and m; the form, however, is so striated and distorted by the development of vicinal faces that no satisfactory measurements could be obtained; it approximates to (110), respectively (110). The form has been verified by Ungemach. The pyramid w is developed to so slight an extent and the crystals are so complicated by polysynthetic twinning that it is impossible to state whether it occurs only in front or only behind; hence it is assumed that both forms, w(111), and w(111), are present.

A fourth crystal showing a marked hemimorphic development is the one described by Ungemach and reproduced in figure 49.

Figure 49 Stibiotantalite showing hemimorphic development. After Ungemach. The crystal is so oriented in the drawing that the brachypinacoid bison top. Forms: b{010}, m{110}, z{150}, h{032}, n{012}, w{111}.

With the exception of the crystals just described, the general habit of the mineral is like that of the normal group of the orthorhombic system, as illustrated by figure 50, in which the forms are represented with ideal symmetry, whereas they all show vertical striations on the pinacoid and prism faces and some rounding of the edges between m and m. One crystal only, figure 50, is shorter in the vertical than in the horizontal direction. The largest crystal of the types illustrated is shown in about natural size in figure 50, which measured in the direction of the a, b, and c axes, respectively, 25 by 6 by 30 millimeters, whereas the remaining crystals average about one-fourth this size. Figure 50 shows in detail one of the corners of the crystal idealized in figure x, it is rather unusual in showing the n and n, and w and w faces with numerous reentrant and salient angles, whereas the m and m faces are finely striated and rounded into one another. At the opposite end of the crystal the n and w faces appear without reentrant angles.

Figure 50 Stibiotantalite simulating holohedral symmetry by twinning. After Penfield and Ford. Forms: b{010}, m{110}, n{012}, w{111}. The brachypinacoid b{010} is drawn in front.

Pyroelectricity.

The pyroelectric phenomena exhibited by all the crystals reveals a complex polysynthetic twinning structure, as the result of which the crystals with few exceptions appear as if they possessed normal orthorhombic symmetry. Each crystal has its own peculiar polysynthetic development, and it seems sufficient to select as types a few examples in which the distribution of the electrically excited surfaces is indicated diagrammatically. (See fig. 51.) The crystals are represented, as it were, unfolded; there is given first a top view, then in turn views of the front, right-hand side, back, and left-hand side. Lower ends have not been represented because, with few exceptions, they are fracture surfaces. As already stated, the crystals were tested for pyroelectricity with a mixture of carmine, sulphur, and lycopodium, with which negatively and positively electrified surfaces are coated, respectively, white by lycopodium and red by sulphur coated with carmine. In the diagrams the negative surfaces are indicated by parallel lines (lycopodium), the positive by cross lines (red, sulphur and carmine); the neutral, brown surface of the crystals is left white. The diagrams illustrate how irregularly the lamellae are intergrown and, to a certain extent, how complex the twinning really is; but the diagrams do not do the subject full justice, for often the lamellae are too thin and the red and the white alternate in bands too narrow to be represented by line drawings.

Figure 51 Distribution of electrified areas on stibiotantalite crystals when cooled. After Penfield and Ford. a, negatively electrified areas; b, positively electrified areas;. c, neutral areas.

The diagrams shown in figure 51 are copies from those given by Penfield and Ford but the legend has been interchanged for the neutral and negative surfaces, as a neutral surface is more easily understood if it be left blank. The corresponding change has of course also been made in the drawings.

Description of forms.

The brachypinacoid b {010} is generally the most prominent of all the forms, has a bright luster, and is usually striated vertically, the striae being rather fine and seldom giving rise to much rounding or irregularity of the surface; on a few crystals the faces appear almost free from striations. Both {100} and { $\bar{1}$00} occur without any apparent difference, except when tested for pyroelectricity, and then it generally appears that the same surface develops two kinds of electricity, owing to twinning and interpenetration.

The prisms m {110} and m' { $\bar{1}$10} are present on all of the crystals and are always striated vertically, owing to polysynthetic twinning and in part perhaps to oscillatory combination, both causes giving rise to a rounding of the edge between m and m', or, as is frequently the case, to a considerable distortion when one prism face predominates over the other. In almost all of the crystals, however, portions of the prismatic faces are quite free from striations, so that good measurements may be had. Any modification of the edge between b and m, was rarely observed. On two crystals distinct replacements, indicating the presence of a prism corresponding tog {130} and g'

{ $\bar{1}$30} were noted, but the faces were too poorly developed to give good measurements, compare figure 48.

The macrodomes n {012} and n' {0$\bar{1}$2} are prominent on all of the crystals, as shown by the figures. A single face is generally composed of both n and n' as already explained. The domes are generally free from striations and dull in comparison with the other faces, appearing as if corroded, but on a few of the crystals they are bright and somewhat striated, not sufficiently so, however, to interfere with measurements. On the Ramona crystals, these faces were all considerably striated. the domes h {032} and perhaps h' {0$\bar{3}$2} occur on only few of the crystals, two of which are shown as nearly as possible in true proportions in figures 47 and 49. On both crystals the surfaces were so dull, seemingly etched, that on the goniometer they gave no reflections of the signal. Owing to the interposition of a twin lamella, the dome h, in front, shown in figure 00, extends only about one-third across the crystal.

The pyramid w {111} appears on only a few of the crystals from Mesa Grande; however, it is present on all of those from Ramona. It is not prominent on the Mesa Grande crystals, but it is well developed on those from Ramona. Its development is so complicated by polysynthetic twinning, that it is difficult to state whether it occurs in front {111}, or behind { $\bar{1}$11}, or in both positions. The pyramid faces are often striated parallel to the edge {111} $\wedge$ { $\bar{1}$11}, as if in oscillatory combination, and frequently distinct reentrant angles occur, (figs. 00, 00, 00), which indicate rather that the striations result, in part at least, from polysynthetic twinning. The pyramid faces generally have bright surfaces, which yield good reflections even when the accompanying dome faces are dull.

A basal place c {001} was observed by Ungemach, though it may have been formed by an oscillatory combination of n $\wedge$ n', or as a result of polysynthetic twinning

Habit.

The crystals of stibiotantalite show four distinct habits with gradation between. These may be described as
(A) Tabular,
(B) hemimorphic,
(C) rectangular prismatic,
(D) equidimensional.

(1) The commonest habit is a tabular on, the crystals being flattened parallel to b {010}, Plate H XXX D shows a view of such a crystal now in the American Museum of Natural History. This crystal has the brachypinacoid b {010} in front. Crystals of this habit are shown in figures 50 and 51.

(2) A second habit forms crystals somewhat prismatic showing distinctly the hemimorphic development of the faces. Figures 47 and 48, taken from Penfield and Ford's paper, and figure 49, reproduced from the article by Ungemach, show the character of these hemimorphic crystals. They are all from Mesa Grande, as all of the observed crystals from Ramona are so twinned as to simulate holohedral symmetry.

(3) Rectangular prismatic crystals are not common. They are formed by repeated polysynthetic twinning so as to yield a vertically striated face apparently plane and normal to the brachypinacoid (Schaller) but in reality composed of repeated minute faces of the two prisms m {110} and m' { $\bar{1}$10}. Plate XXV C, shows such a rectangular crystal in the A.F. Holden collection. It has a length of 56 mm, a thickness of 17 mm,

165

and a width of 9 mm.

(4) The equidimensional crystals or such as are nearly so comprise the crystals of ordinary combination, which are about prismatic and also such ones as are bounded by rarer forms. To the latter class belongs the crystal figured by Penfield and Ford (their fig. 16) and reproduced here in figure 52. Likewise, the complex crystal shown by Ungemach (his figs. 1 and 2) and reproduced in figure 53 belongs here.

Description of crystals.

The general appearance of the crystals has already been given so that it will suffice to repeat briefly the descriptions of the unusual crystal figured by Penfield and Ford and the complex one described by Ungemach. The small crystals from Ramona may also be given a short note.

The crystal, reproduced in figure 52, is totally different in habit and combination from the other crystals described by Penfield and Ford. It measures about 5 cm in length, (b axis of Schaller), 4 cm in height, c axis, and 3 cm in thickness (a axis of Schaller). It weighs 150 grams and is one of the largest crystals found.

Figure 52 Stibiotantalite from Himalaya mine, Mesa Grande. After Penfield and Ford. Forms: b{010}, m{110}, 8{101}, w {111}.

It was picked up in two pieces, and the fracture surfaces do not appear fresh, as if recently broken in taking the crystal from the matrix. Originally, :it must have been quite symmetrical in. development and in shape about as shown in figure 52. It was attached at the lower left-hand comer to pink tourmaline, bits of which are still adhering to it. The upper and the lower edges and a considerable portion of the lower, right-hand comer have been broken off. The b and b' faces to the right and left are fresh-looking cleavage surfaces. Whether the pinacoids b and b' were originally present, as shown in figure 52, or whether adjacent faces came together at the acute edges, cannot be told. The habit of this crystal is entirely different from that of the others, and the peculiarities of its surface are also different. The macrodome ǝ {101} has been observed only on this and two other crystals described by Ungemach. The prism m is not striated vertically. The surfaces are all etched, so that only measurements with a contact goniometer may be had, but these all agree with those obtained from other crystals. The best formed etchings on the prism m are rather deep depressions, shaped about as shown in figure 00, though the majority are much more rounded, in places they join one another, giving rise to furrows running irregularly over the surface. The etchings on the macrodome ǝ are long depressions, some of them quite deep; those on the pyramid ware also long, but somewhat comma-shaped, the tails pointing away from the edge w Λ ǝ. The crystal is light yellowish-brown in color, more transparent than any of the others, and has a specific gravity of 6.69.

The crystal is a polysynthetic twin, though the outward form gives no evidence of it The two large fragments that make up the specimen do not of themselves exhibit pyroelectricity, probably because of numerous cracks running through the material; but a small homogeneous fragment, when tested, exhibited alternating bands of positively and negatively excited material, remarkably uniform and not over 2 mrn in width.

Throughout a portion of its interior the crystal is curiously cavernous, although the exterior is firm and consists of remarkably pure, transparent material. The cavity looks as though it had been eaten out by some solvent and is lined with some secondary material, which without endangering the specimen could not be gotten out in sufficient quantity for a satisfactory test. Resting on this secondary material are a few

very minute pyramids of cassiterite.

The crystal described by Ungemach (reproduced in fig. 53) measured 22 mm by 19 mm by 9 mm and weighed 12.5 grams. It is very rich in faces showing all the forms of stibiotantalite except z The c{150}. In addition, the vicinal forms {1.17.1}, {0.23.1}, {1.i3.0}, {1.19.0}, are present as small facets.

Figure 53 Stibiotantalite from Himalaya mine, Mesa Grande. After Ungemach. The crystal is so oriented that b{010} is on the top.

The crystals from Ramona (figs. 54, 55, 56) are all tabular and show the same combination of forms: b {010}, m {110}, n {021 }, w { 111 }, The habit and common appearance of these crystals is shown in figure 54.

Figure 54 Stibiotantalite from Little Three mine, Ramona. Forms: b {010}, m {110}, n {021}, w {111}.

The pyramid w {111} is developed unequally on some crystals, as is shown in figure 55.

Figure 55 Stibiotantalite from Little Three mine, Ramona. Shows unequal development of the pyramid w {111}.

This inequality in development of the faces of the pyramid may lead to a suggestion of hemimorphism in the direction of the c axis. Figure 56 illustrates a crystal on which the pyramids are entirely absent from the lower side of the crystal.

Figure 56 Stibiotantalite from the Little Three mine, Ramona. Shows apparent hemimorphic development of the pyramid. The b {010} face is drawn in front.

In some of the crystals the color distribution is very marked. This is especially well developed in the crystal shown in figure 56 in which the colors are arranged as shown in the diagrammatic sketch (fig. 57). The crystal extinguishes as one unit and does not show any optical differences in the variously colored parts.

Figure 57. Shows arrangement of color in stibiotantalite crystal shown in figure 56.

In their other characteristics the crystals from Ramona resemble those from Mesa Grande. The brachypinacoids are bright and strongly striated. The prism faces are generally bright and yield distinct reflections. The domes and pyramids are dull and yield a very poor reflection or more generally none at all. A steplike development of the dome n {021}, similar to that described by Penfield and Ford, is well developed on one crystal , showing that it is composed of twins having n and n' respectively, on top.

Physical properties.

The well-developed cleavage is parallel to the large face, after which most of the crystals are flattened. This cleavage face was taken as the macropinacoid by Penfield and Ford, but in the orientation here chosen it becomes (similar to columbite) the brachypinacoid b {010}.

The density of the mineral varies as the proportion of columbium and tantalum oxides change. It has a minimum value of about 6.6 and a theoretical maximum density

for the pure antimony tantalite (Sb2O3-Ta2O5) of 7.90 (as calculated by Penfield and Ford).

The color is a rich dark-brown; a few crystals are nearly black; others are light brown. On some of the small crystals from Ramona, the color is almost a yellow. The luster is resinous to adamantine. The fragments of light-brown color are identical in appearance with the sphalerite from Picos de Europa in Spain.

Optical properties.

The optical properties were determined by Penfield and Ford on a crystal with a density of 6.818. The axial plane of the orthorhombic mineral is parallel to b {010} (in the new orientation adopted in this report) and the acute positive bisectrix is normal to c {001}. Therefore: a axis= X, b axis= Y, c axis= Z. The constants measured by them are:

Optical constants of stibiotantalite.

Light	Refractive indices			Birefringence	Axial angle
	α	β	γ	$\gamma-\alpha$	2V calculated
Lithium--	2.3470	2.3750	2.4275	0.0805	70°40'
Sodium--	2.3742	2.4039	2.4568	.0826	75°05'
Thallium	2.4014	2.4342	2.4876	.0862	77°38'
Sodium---	2Ha (measured) = 119°10', therefore 2V = 75°58'.				

The optical properties are characterized by Penfield and Ford as follows, the properties of stibiocolumbite being included here·with for comparison: The mineral is characterized by an unusually high index of refraction, the values y for yellow, 2.4568 and 2.4588, being somewhat higher than that of diamond, 2.418, and considerably above that of sphalerite, 2.369, yet so near the latter that, both minerals being of the same color and possessing good cleavage, fragments of the two look alike. An unusually strong dispersion, r < v, is a marked feature of the mineral, and also a high birefringence, y-a. for yellow being 0.0826 for stibiotantalite and 0.0611 for stibiocolumbite.

The divergence of the optical axes, 2V, is so great that 2E cannot be observed; in fact, the mean index of refraction of the mineral is so far above that of our highest refractive liquids that it was with the greatest difficulty that 2Ha could be observed. This was owing in part to the fact that the sections, prepared from the same crystals from which the prisms were cut, contained some dark inclusions that interfered with the transmission of light. 2Ha, therefore, was measured only for sodium light, the illumination from lithium and thallium flames being too weak to yield distinct interference figures. It seems rather anomalous to have 2Ha acute as high as 119° for stibiotantalite and 113° for stibiocolumbite, but this is owing to the very high refractive index of the mineral. In both crystals the agreement between the values of 2 V, as calculated from the three indices of refraction and from 2Ha, are as satisfactory as could be expected in view of the difficulties encountered in preparing the prisms and sections and in making the measurements. The substitution of Nb2O5 for Ta2O5 causes a slight increase in the values of the indices of refraction, a decrease in birefringence (γ- α) and, except in the case of thallium, a decrease in 2V. The dispersion is much more marked in stibiocolumbite, the difference of 2V for green and red being about 7°; whereas, for stibiotantalite it is about 4°.

Chemical composition.

Two analyses have been made on the stibiotantalite from Mesa Grande and the results obtained are shown below.

Analyses of stibiotantalite from Mesa Grande.

Sample 1 (Penfield and Ford, analysts)			Sample 2 (Foote and Langley, analysts)		
Constituent	Percent	Ratio	Constituent	Percent	Ratio
Ta_2O_5------	33.86	0.0759	Ta_2O_5------	41.92	0.0939
Cb_2O_5------	21.47	.0801	Cb_2O_5------	16.19	.0604
Sb_2O_5------	44.26	.1536	Sb_2O_5------	40.95	.1421
Bi_2O_5------	0.32	.0007	Bi_2O_5------	0.60	.0013
Total---	99.92		Total---	99.66	
Density 6.72			Density 6.80		
Consists of 55.5 per cent stibiotantalite. Consists of 44.5 per cent stibio-columbite			Consists of 67.2 per cent stibiotantalite. Consists of 32.8 per cent stibio-columbite.		

It is remarkable, as already mentioned under stibiocolumbite, that these two samples should show so little difference in their densities as compared with the larger difference in their chemical composition.

According to Penfield and Ford the pyrognostic properties of the mineral are as follows:

Stibiotantalite, when heated intensely at the top of the blue flame, is fusible at about 4 and imparts to the flame a pale bluish-green color due to volatilization of antimony. After part of the antimony is driven off there is left an infusible mass of columbium and tantalum oxides generally darkened by antimony. If the flame from the mineral is directed against a piece of charcoal a considerable coating of oxide of antimony collects on the coal.

When fused with 3 or 4 times its volume of sodium carbonate on charcoal, a coating of antimony oxides and small globules of metallic antimony are obtained. The powdered mineral is not appreciably attacked by ordinary acids, not even by boiling concentrated sulphuric acid, but it is readily soluble in hydrofluoric acid. It is unchanged when heated in closed and open tubes and gives no characteristic reactions with the fluxes. The mineral may be readily identified and told from columbite by the following reaction: Dissolve a little of the powdered mineral in a small quantity of hydrofluoric acid; add a large excess of hydrogen sulphide water, then the red antimony sulfide will be precipitated.

Apatite

Localities.

Apatite has been identified on a specimen from the Katerina mine on Hiriart Hill, at Pala. It forms a grayish-green compact mass without any crystal faces and was collected with specimens of triplite, lithiophilite, and sicklerite. It has also been found at Rincon. The most abundant occurrence of the mineral is at Mesa Grande where it has been found at all of the producing mines--the Himalaya, the San Diego, and the Esmeralda.

Crystallography.

The mineral shows two very distinct habits or types of crystals. They are either stout tabular or long prismatic. The base and prism are the only forms observed by the writer on any of the crystals. Rogers[97] mentions thin to thick tabular crystals of a pale dirty green color. They were obtained from the Victor mine, at Rincon, and the forms observed by him are $\{0001\}$, $\{l0\bar{1}0\}$, $\{1121\}$, $\{10\bar{1}2\}$, $\{10\bar{1}1\}$, and $\{3141\}$.

The stout tabular crystals from Mesa Grande (Plate. XXV H) reach a size of several centimeters. One specimen measured 38 mm high (c axis) and 41 mm across. Another crystal, associated with tourmaline and illustrated in Plate XXV H measured 22 mm high and 32 mm across. A nearly complete crystal from the San Diego mine was even larger.

The long prismatic crystals (Plate XXV G) reach a length of nearly a 10 cm and are from 1 to 1-1/2 cm thick. Two smaller crystals from the Esmeralda mine measure 22 mm and 17 rnm high and 11 mm and 9 mm thick, respectively.

The faces of c$\{0001\}$ are mostly dull and rough; whereas, the prisms m$\{1010\}$ are marked by vertical striations, short vertical grooves, and on some specimens by prominent irregular canal-like markings. On a few specimens, horizontal bands are also prominent (Pl. XXV, F). Liquid inclusions, some of them with bubbles, are abundant. The two habits are shown in the accompanying figure 58 and illustrations of these crystals are also shown in Plate XXV F, G, H.

Figure 58 Apatite from Mesa Grande. a, stout tabular habit, b, long prismatic habit. Forms: c$\{0001\}$, m$\{1010\}$.

General Properties.

The crystals have a characteristic and unusual color, similar to that of the associated fluorite. Different specimens vary somewhat in shade but the color is close to the hydrangea red, (Plate XVII of Ridgway's Color Standard). Some of the crystals are capped by a thin layer of light-colored material as in the specimen shown in Plate 000.

The mineral is transparent in small pieces and has a conchoidal fracture that yields vitreous glassy fragments when a specimen is broken. The dichroism is marked, changing from a red to a brown color.

The refractive indices were determined and found to be as follows: A partial chemical analysis of a specimen from the Himalaya mine, Mesa Grande, showed that the material was a pure fluorapatite, chlorine, carbonic acid, and water (as hydroxyl) being absent. A colorimetric determination of manganese gave 0.38 per cent MnO.

Amblygonite

The minerals, which with amblygonite, form a closely related chemical groups, are as follows:[98]

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[97] Rogers, A.F., Minerals from the pegmatite veins of Rincon, San Diego Co., California: School of Mines Quarterly, vol. 31, p. 217, 1910.

[98] Schaller, W.T., Nomenclature of the amblygonite group: Journal of the Washington Academy of Sciences, vol. 3, p. 152, 1913.

Amblygonite Li(AlF) PO4.
Montebrasite LiAl(OH) PO4.
Fremontite[99] NaAl(OH) PO4.
Durangite Na(AlF) AsO4.

The first three of these-amblygonite, montebrasite and fremontite-are found together in isomorphous mixtures with generally one of the three in predominating amount.

In California this group occurs at several localities in the gem tourmaline field, notably at Pala where in the Stewart Mine a large body of many hundred tons weight was uncovered and taken out. An analysis of a typical example of this lithia ore, showed it to be a mixture of amblygonite and montebrasite with the latter greatly in excess. The two minerals can be readily distinguished by chemical tests. On heating a small fragment in a closed tube the amount of water given off can be closely judged. If only a little water is obtained and the fluorine compound is in excess; the mineral is amblygonite or the hydroxy-amblygonite variety. If, on the other hand, considerable water is given off, then the hydroxyl compound is in excess and the mineral is montebrasite or the fluoro-montebrasite variety. A further diagnostic property is given by Lacroix,[100]96 who gives the following values for the refractive indices of the two minerals.

Amblygonite			Montebrasite		
$\alpha = 1.578$	$\beta = 1.593$	$\gamma = 1.597$	$\alpha = 1.600$	$\beta = 1.611$	$\gamma = 1.620$
$(\gamma-\alpha) = 0.019$			$(\gamma-\alpha) = 0.020$		

Chemical tests were made on all the supposed amblygonite specimens from California and every one of them gave considerable water in a closed tube. Tested optically, the following values were obtained for the refractive indices.

For one specimen (Stewart mine) gave 1.595; two others (Hiriart Hill) gave values very slightly below 1.597. Both the other indices (a and y) gave values higher than 1.597, one of the indices being considerably higher. Assuming the birefringence (0.020) as given by Lacroix to be correct and using this value for determining y, the following are the approximate values obtained.

Refractive indices montebrasite.

Locality			β	γ
Stewart mine, Stewart Hill, Pala				
Katerina mine, Hiriart Hill, Pala	.595	.60	.615	
Vanderburg-Naylor mine Hiriart Hill, Pala	1.60 1.615	.605	.62	

On comparing these results with those given by Lacroix it is seen that, as confirmed by the chemical test, all the California mineral tested is montebrasite and not amblygonite, as defined at the beginning of this description. More accurately, it is a fluoro-montebrasite as a small amount of the hydroxyl is replaced by fluorine.

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[99] In the original discussion this mineral was called natrarnblygonite
[100] Lacroix, A Mineralogic de la France, vol. 4, p. 414, 1916.

Localities.

Amblygonite has been found only at Pala and at Rincon. At the latter place, a few small masses of it were found; however, at Pala, it occurred in several of the mines in similar small masses and also in one large mass containing originally hundreds of tons of the mineral. Its general appearance is so similar to feldspar that amblygonite may have been mistaken for feldspar at different mines and no account taken of its presence.

At Pala, the mineral is found in its greatest abundance at the Stewart Mine. A number of small pieces not weighing over several pounds each, were found close to the large body of massive amblygonite which was mixed as an ore of lithium. The occurrence of this large body has already been described on page 000. No amblygonite has been definitely identified by the writer from any other mine on Stewart Hill or on Pala Chief Hill. On Hiriart Hill it has been noted as small irregular masses in the Katerina, Vanderberg-Naylor and Hiriart mines.

General description.

All the amblygonite from this field is cleavable, massive. The cleavage surfaces vary in size, some being very large. The largest are measured at 5 cm across, though this was probably by no means a maximum. A careful search of the abundant material failed to show any distinct crystals. The mineral is white, opaque, often with a grayish cast to it. The samples from the Katerina mine, or Hiriart Hill (Specs. Nos. 129 and 229) are more glassy and vitreous than the ore from the Stewart mine, but, in general, the samples from the different mines are very similar in appearance. The associations of amblygonite are well illustrated by Specimen No. 163, from the Stewart mine. This specimen shows a small piece of cleavable amblygonite adjoining a larger piece of massive quartz to which a little altered feldspar adheres. Long prisms of pink tourmaline penetrate the quartz and one such prism, nearly 7 cm long lies partially embedded in the amblygonite. Much of the tourmaline has altered to pink clay--halloysite--where the amblygonite is perfectly fresh and unaltered giving an intense crimson flame when fused before the blowpipe. The conditions that caused the pink tourmaline to alter into clay, therefore, were without effect on the amblygonite.

Another mode of occurrence of the amblygonite deserves to be described. In various part of the pegmatite of the Stewart mine, are small areas, seldom extending over a 10 cm of soft flour-like substance embedded in which are hard angular fragments of some mineral. These fragments were identified as amblygonite. They have a corroded exterior, as if the amblygonite had been partially dissolved while the interior of the fragments is fresh amblygonite not showing any sign of alteration. The soft flour-like powder is clay and very fine feldspar and represents doubtless, a phase of the feldspar more or less kaolinized. The original condition probably showed a firm rock composed of feldspar and amblygonite. Subsequent conditions were such that the feldspar was largely changed to clay, producing the powdery condition now called "amblygonite powder" though the powder itself does not consist of amblygonite. The kaolinization conditions existing here had only a slight solvent action on the amblygonite, which they were unable to alter in any way. Several other similar areas of powdery material (Spec. No. 426) were essentially incompletely kaolinized feldspar free from any amblygonite.

Chemical Composition.

An analysis of the amblygonite forming part of the ore body at the Stewart mine was analyzed with the results shown below. Care was taken to obtain a pure sample.

Analysis of amblygonite, Stewart Mine, Pala.
(Analyst, W.T. Schaller]

P_2O_5----------	48.83
Al_2O_3-------	33.70
Fe_2O_3----------	.12
MnO----------	.09
MgO----------	.31
Li_2O----------	9.88
Na_2O----------	.14
H_2O----------	5.95
F---------------	2.29
Subtotal--	101.31
Less O-------	.96
Total--	100.35

The mineral is, therefore, a pure amblygonite with nearly 10 percent of lithia. Regarding fluorine plus the hydroxyl as isomorphous, the later greatly predominates over the fluorine. The water was determined by igniting the mineral with lead oxide, previously heated nearly to fusion. Three determinations gave the lost of weight due to the escape of water, as 5.89, 6.01, and 5.95 percent. The loss of the mineral on ignition was 8.03 percent; thus, nearly equaling the sum of the water and fluorine content

Triplite

Localities.

Triplite has been definitely identified only from Hiriart Hill at Pala. I have seen specimens labeled "triplite" that were reported as coming from Bonsall and from Rincon, but I was not able to confirm the label. The mineral has not been observed by me at any place on Stewart Hill. It is an original mineral of the pegmatite and is found in granular masses and in embedded grains in the pegmatite not directly associated with any other phosphate. No alteration product of it has been identified.

Physical properties.

The triplite from Hiriart Hill shows imperfect cleavage surfaces; whereas, in thin section straight cleavage lines are well developed. The hardness about 5. The density was determined on several different samples of the mineral by means of the Jolly balance with the following results:

Density of triplite from California

Color	Density
Black	3.811

Black	3.886
Black	3.834
Black	3.838
Garnet red	3.839
Garnet red	3.820
Average	3.84

The color is either a light brown, garnet red; or black--with all possible gradations. The light brown occurs as irregular bands in the garnet ,red; the garnet red is in large massive pieces or in small grains scattered through the rock (quartz, feldspar) or the more compact phase of the triplite; the black variety occurs in large massive pieces and show the best developed cleavage.

The mineral is colorless in this section. In thicker pieces a slight pleochroism in brown is noticed. The birefringence is low, about 0.01. The refractive indices were determined to be about as follows, $\alpha = 1.64$, $\gamma = 1.65$; therefore, $\gamma - \alpha = 0.01$.

Chemical composition

The mineral fuses readily before the blowpipe, forming a bubbling bead. Heated in a dosed tube it decrepitates, gives off only a trace of water and generally deposits a slight white ring. It is readily soluble in acids.

The analysis of a specimen of the black triplite gave the following results.

Analysis of triplite, Hiriart Hill, Pala.
[W.T. Schaller, analyst.]
---- indicates, element not detected.

	Fraction 1	Fraction 2	Fraction 3	Ratios
FeO--------	3.38	3.25	3.32	3.89 or 4 x 0.97
MnO------	52.01	51.70	51.86	
CaO--------	3.29	3.46	3.38	
Fe_2O_3----	None	---	None	
P_2O_5------	31.12	---	31.12	1.02 or 1 x 1.02
H_2O------	0.97	0.76	.87	2.02 or 2 x 1.01
F----------	8.27	---	8.27	
Residue, insoluble	0 .62	---	0.62	
Residue, Mn_2O_3	3.45	---	3.45	
Subtotal			102.89	
Less O--			- 3.48	
Total----			99.41	

The ratios of the above analysis agree well with the formula of triplite, namely 4 MnO ·P2O5 ·F2 or Mn(MnF)PO4. The loss of water was as follows: at 110°, 0.09 percent; at 180°, 0.19 percent; on ignition. 0.76 percent.

Altered triplite has not been found in this locality though the presence of Mn2O3, probably as manganite, scattered throughout the mineral would indicate that like the other manganese phosphates, its final alteration product is manganite.

Lithiophilite

Localities.

The mineral lithiophilite, representing the manganese end of an isomorphous series of which triphylite is the corresponding iron end, has hitherto been found only at the original locality at Branchville, Connecticut.[101] In the summer of 1904 numerous specimens of the mineral were collected at Pala though no announcement of the occurrence of the mineral was published until 1912, during which time opportunity was had of studying the alteration products as. well as the mineral itself. Lithiophilite has also been reported from the Black Hills in South Dakota[102] where a considerable amount of it was obtained. A specimen of what was said to be the material extracted was tested by me and found not to be that mineral. The California occurrence is, therefore, the second one for this mineral as the Maine and South Dakota localities must remain doubtful until proven correct.

Numerous large black crystals of lithiophilite, in their present condition almost entirely altered to a complex of secondary hydrous iron and manganese phosphates were found near the mouth of the west tunnel of the Stewart mine at Pala. The outside layer of these crystals consists of massive black manganite. The presence of lithiophilite could be established in only two cases; in all the other specimens the original mineral had completely altered to palaite, and other secondary minerals. Several specimens retained the crystal form of the original mineral, and these are described in the following section.

The mineral has also been found on Hiriart Hill, Pala. A massive specimen of a light colored phosphate was collected here in 1904 and on my return to Washington a powdered sample of it was prepared for analysis, which however could not be undertaken at that time. Before the investigation of it could be resumed, the specimen was lost in a fire. A tube of powdered material was saved, however, and its analysis identified the mineral as lithiophilite, though its physical properties, could not be determined.

Crystallography

General description

The lithiophilite from Connecticut did not show any definite crystals although some of the masses had a somewhat crystalline aspect. In the California locality, several large imperfect crystals were obtained that were sufficiently developed to permit of their determination.

The crystals are large, and the present size of the four best developed ones, described below, is as follows with the lengths given in centimeters:

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[101] In Dana's System of Mineralogy, 6th ed., 1892, p. 757, a second locality is given as Tubb's farm, Norway, Maine. I have not been able to find any other published reference to this locality.

[102] See Zeigler, V., Min. and Sci. Press, vol. 108, April 1, 1914.

Crystal No.	Length, direction of c axis	Width, direction of b axis	Thickness, direction of a axis	Weight, in grams
1------	12 1/2	8	5	712
2------	9	5 1/2	7	373
3------	9	8	5	467
4------	8	4	4	165

These measurements refer to the present size of the specimens, the complete crystals having originally been much larger. The largest specimen consists of two crystals in parallel position and is illustrated, natural size on

Plate XXVI A; whereas, the crystal form is shown in figure 59.

Calculation of elements.

The crystal faces are so rough and uneven that measurements could be made only with a contact goniometer. These are necessarily approximate but they represent the best values that can be obtained at present.

It has been assumed that the cleavage directions of lithiophilite are the same as those of triphylite namely c {001} and b {010}, and these directions have helped materially in orienting the crystals. These cleavages are very well shown in crystal No. 4, as shown in its photograph, Plate XXVI B. Lithiophilite is orthorhombic so that only two constants are needed for the axial ratios, namely a and c. These are first given as Po and Qo. representing c/a and c, respectively, as these values are more convenient in the calculations.

Determination of Po. lithiophilite.

Crystal No.	Angle measured	Po
1	{001} $\wedge$ {101}=45°	1.1504
3	{001} $\wedge$ {203} = 39°	1.2137
3	{001} $\wedge$ {302} =61°	1.2027
4	{001} $\wedge$ {101} = 51°	1.2423
	Average- 1.2023	1.2023

Determination of Qo, lithiophilite.

Crystal No.	Angle measured	Qo
1	{001} $\wedge$ {021} = 45°	0.5000
2	0.5000	0.5362
2	{001} $\wedge$ {021}= 47°	0.5362
2	.5362	0.5362
3	{001} $\wedge$ {021} = 47°	0/5362
3	{001} $\wedge$ {021} = 47° .5362	
3	{001} $\wedge$ {021} = 47°	0.5553

4	.5362	0.5362
4	{001} ∧ {021} = 47°	0.5362
4	.5362	0.5548

{001} ∧ {021} = 48°
.5553
{001} ∧ {021} = 47°
.5362
{001} ∧ {021} = 47°
.5362
   {001} ∧ {031} =
59°
Average   0.5364

The average values obtained from the measurements are Po= 1.2023, Qo = 0.5364. These yield the following for the axial ratios for lithiophilite:

a : b : c = 0.4461 : 1 : 0.5364.

These values are very close to those given for triphylite which are

a : b : c = 0.4348 : 1 : 0.5265.

Forms and angles.

The forms identified on these crystals are as follows:[103]

c {001}   m   f{203}   p
b {010}   {120}   031}   .n{   e {101}
           k{1
        40}   v{302}

All of these, except k {140}, f {203} and p {111} are also to be found recorded for triphylite.

The comparison of the measured and calculated angles is given below.

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[103] Transcribers note: Schaller has identified as the a axis what is presently listed as the c axis in most modem, 1995 texts, such as Dana's System of Mineralogy, Seventh edition; therefore, his c axis equals the a axis in modern texts.

Crystal No. 1 (Figure 59 and Plate XXVI *A*).

Form	Angles	
	Measured	Calculated
m {110} $\wedge$ m' {110} =	51°	48°04'
c {001} $\wedge$ ε {021} =	45°	47°00'
c {001} $\wedge$ e {101} =	49°	50°15'

Crystal No. 2 (Figure 60).

Form	Angles	
	Measured	Calculated
b {010} $\wedge$ c {001} =	87°	90°00'
c {001} $\wedge$ ε {021} =	47°	47°00'
c {001} $\wedge$ ε {021} =	47°	47°00'
ε {021} $\wedge$ ε' {0$\overline{2}$1} =	94°	94°00'
b {010} $\wedge$ m {110} =	66°	65°58'
h {010} $\wedge$ l {120} =	44°	48°16'
c {001} $\wedge$ e {101} =	53°	50°15'

Crystal No. 3 (Figure 61).

Form	Angles	
	Measured	Calculated
c {001} $\wedge$ ε {021} =	47°	47°00'
c {001} $\wedge$ ε {021} =	48°	47°00'
c {001} $\wedge$ f {202} =	39°	37°43'
c {001} $\wedge$ v {302} =	61°	61°00'

Crystal No. 4 (Figure 62 and Plate XXVI B

Form	Angles	
	Measured.	
m {110} $\wedge$ m' {1$\overline{1}$0} =	45	48°04'
c {001} $\wedge$ s {021} =	47	47°00'
c {001} $\wedge$ s {021} =	47	47°00'
c {001} $\wedge$ n {031} =	59	

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The following table gives the coordinate angles for lithiophilite to which are added the forms and angles of triphylite for comparative purposes. The angular values of lithiophilite, are, as has been already stated, only approximations.

Forms and coordinate angles for lithiophilite and triphylite.

Symbol	Lithiophilite $a = 0.4461$; $c = 0.5354$; $p_0 = 1.2023$		Triphylite $a = 0.4348$; $c = 0.5265$; $p_0 = 1.2109$	
	ϕ	ρ	ϕ	ρ
c {001}	---	0°00'	---	0°00'
b {010}	0°00'	90°00'	0°00'	90°00'
k {140}	29°16'	90°00'	---	---
l {120}	48°16'	90°00'	48°59'	90°00'
m {110}	65°58'	90°00'	66°30'	90°00'
ε {021}	0°00'	47°00'	0°00'	46°28'
n {031}	0°00'	58°08'	0°00'	57°39'
w {102}	---	---	90°00'	31°11'
f {203}	90°00'	38°43'	---	---
e {101}	90°00'	50°15'	90°00'	50°27'
v {302}	90°00'	61°00'	90°00'	61°10'
p {111}	65°58'	52°48'	---	---

[NOTE: Schaller has identified as the a axis what is presently listed as the c axis in most modem texts, such as Dana's System of Mineralogy, Seventh edition; therefore, his c axis equals the a axis in modern texts.)

Habit.

The habit of the crystals is short prismatic and the relative development of the different faces can be seen by reference to the crystal drawings. (Figures 59-62).

Figure 59 Lithiophilite crystal no. 1. Forms: c {001}, b {010}, p {140}, m {110}, 1 {120}, s {021}, n {031}, f {203}, e {101}, v {302}, p {111}.

Figure 60 Lithiophilite crystal no. 2. Forms: c {001}, b {010}, p {140}, m {110}, 1 {120}, s {021}, n {031}, f{203}, e {101}, v{302}, p {111}.

Figure 61 Lithiophilite crystal no. 3. Forms: c {001}, b {010}, p {140}, m {110}, 1 {120}, s {021}, n {031}.f{203}, e {101}, v{302}, p{111}.

Figure 62 Lithiophilite crystal no. 4. Forms: c {001}, b {010}, p {140}, m {110}, 1 {120}, s {021}, n {031}, f{203}, e {101}, v{302}, p {111}.

On crystal no. 4, figure 62, there are indications of two more pyramidal faces in the zone b (010): e (101), but these crystal faces were too small and uneven for their determination.

Optical Properties.

The general physical properties could not be determined on the California mineral because suitable material was not available. Neither could any determinations be made of the optical constants, but these can be given here for comparison with those

of the other minerals. In two thin sections was noted an abundance of a massive colorless, phosphate; this can be either lithiophilite, palaite, or colorless hureaulite, if optical tests alone had to be relied on. These particular specimens were tested chemically, and, as a strong lithium flame was obtained, it is assumed that some lithiophilite, at least, was present. No decisive test was had, however, that any of the colorless phosphate is lithiophilite: it may possibly be all palaite.

Refractive indices of lithiophilite from Connecticut were determined by Penfield and Pratt as follows:[104]

Refractive indices of lithiophilite from Connecticut,
--- means no measurements could be made or were determined.

Color of mineral	Percent FeO	Light	n_x	n_y	n_z	n_x-n_z
		Red	---	1.672	---	---
Salmon	4.24	Yellow	---	1.675	---	---
		Green	---	1.682	---	---
Light		Red	---	1.674	---	---
clove-brown		Yellow	1.676	1.679	1.687	.011
		Green	---	1.682	---	---
Light clove-brown		Red	---	1.678	---	---
with bluish cast		Yellow	---	1.682	---	---
		Green	---	1.687	---	---

The light clove-brown material with 9.42 percent FeO is chemically similar to the California mineral, and the optical constants given in the table above are, therefore, used in the study of the material from Pala. The following compilation of certain properties of the three minerals (lithiophilite, colorless hureaulite, and palaite) shows how difficult it is to distinguish them in a thin section by optical tests. This difficulty is greatly increased by the fact that both hureaulite and palaite are in a way pseudomorphous after lithiophilite and therefore retain such properties as cleavage, which then appear as truly belonging to the mineral observed.

[NOTE.- Schaller's axial nomenclature here matches that in Dana's System of Mineralogy, Seventh edition]

Mineral	Color in thin section	Pleochroism	Indices of refraction			
			n_x	n_y	n_z	n_z-n_x
Lithiophilite----------	Colorless	None	1.676	1.679	1.687	.011
Colorless hureaulite	Colorless	None	1.656	1.660	1.672	.016a
Palaite----------------	Colorless	None	1.652	1.656	1.660	.008

a) The values are those of the colored, strongly pleochroic hureaulite. It is suggested in the text that the refractive indices and birefringence increase with the intensity of the color and pleochroism (due to the presence of Fe_2O_3). The values here given are therefore, probably somewhat higher than the true values of pure colorless hureaulite.

The colorless mineral observed in thin sections of the altered material and which for chemical and other reasons is referred to lithiophilite, shows the following optical

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[104] Penfield, S.L., and Pratt, J.H. Effect of the Mutual Replacement of Manganese and Iron on the Optical Properties of lithiophilite and triphylite. American Journal of Science, 3rd ser., vol. 50, 1895, p. 337.

properties: The mineral is a granular aggregate of pieces without any definite shape. There is one fairly good cleavage and a second one, much poorer, normal to it. None of the cleavage lines are perfectly straight. There are also many irregular cracks. In one distinct single unit, two cleavages were noted that were accurately normal to one another. In other pieces the cleavage lines were so irregular as to suggest that they were simply nearly straight cracks. The extinction against these so-called cleavage lines is very variable. In many places, the extinction is parallel to the cleavage; at other places it is very much inclined thereto. Much of the material is remarkably clear and free from any dust-like inclusion. Other pieces are remarkably full of inclusions, but all these consist of the alteration products. The double refraction is low, the interference colors resembling those of the feldspars. In some pieces the birefringence is very low approaching nearly zero. The individual pieces, that is those which are one unit crystallographically, are all too small to yield any optical data of value.

It seems as if the original mineral had broken into a granular aggregate of small pieces of irregular shape and variously oriented. The mineral is identified as lithiophilite though it may be that a mixture of two minerals is present-namely, lithiophilite (parallel extinction), and palaite (inclined extinction).

It may not be out of place to correct an error in the optical properties of triphylite as given by Lacroix.[105] He quotes from Penfield and Pratt and gives the values 1.692 (a misprint for 1.697), 1.702, and 1.707 as representing the three indices, nx, ny, and nz. As a matter of fact, these three figures give the values for just one axial measurement by red, yellow, and green light, respectively. Therefore, the value of the birefringence, 0.015 given by Lacroix, is wrong and is to be stricken out.

Chemical composition.

The chemical composition of the lithiophilite from the Stewart mine could not be determined, as it is almost entirely altered to other minerals. The mineral into which lithiophilite directly alters are three: namely, stewartite, palaite, and sicklerite. The composition of stewartite and sicklerite from the Stewart mine is unknown; that of palaite has been determined. The percentages of FeO and MnO in palaite are 7.48 and 40.87, respectively, and it may be safely assumed that a similar amount was present in the original lithiophilite.

The lithiophilite from Hiriart Hill, Pala, has been analyzed as the tube of powdered material was not lost in the fire which destroyed the specimen. Subsequent microscopic examination of this finely powdered material showed it to be very impure. These impurities could not be determined though they seemed to be sicklerite, hureaulite, and possibly others. The analysis of the lithiophilite is as follows:

Analysis of lithiophilite, Hiriart Hill, Pala.
    W.T. Schaller, analyst.
 ---, means that the constituent was not detected. A query (?) indicates that Schaller did not enter any data in the original manuscript.

Constituent	Sample 1	Sample 2	Sample 3	Average
FeO-------- .	12.53	12.54	---	12.54
MnO-------		30.71	30.54	30.72	30.66
CaO--------	0.38	---	---	0.38

---

[105] Lacroix, A. Mineralogie de la France, vol. 4, p. 362, 1910.

Fe_2O_3-----	2.24	---	---	2.24
Li_2O-------	3.73	(?)	(?)	3.73
Na_2O------	4.97	(?)	(?)	4.97
H_2O-------	1.28	1.39	1.39	1.35
P_2O_5------	42.92	43.10	---	43.01
Insoluble	0. 5	0.30	---	0.43
Total---				99.31

The analysis indicates an impure lithiophilite. The presence of nearly 5 percent of soda is noteworthy. It shows that the mineral is a mixture of lithiophilite and natrophilite, the very rare soda equivalent of lithiophilite. It is probable that among its alteration product is some alluaudite, which is noted by Lacroix, [106] is to be regarded on as an alteration product of natrophilite on account of its sodium content, natrophilite and not lithiophilite being the alteration product, as has been previously assumed.

The small percentage of water given in the analysis is much more readily expelled than for most of the other associated minerals. Practically all of it was given off at 180°, the values obtained being: at 110°, 0.70 percentile total loss; at 180°, 1.29 percent total loss, and on ignition 1.39 percent total loss.

The lithiophilite from the Stewart mine is altered to a complex of minerals nearly all of which are practically free from lithium. The lithiophilite from Hiriart Hill has on the contrary, altered to sicklerite, which still retains nearly half the lithium present in the original mineral. These alterations are described in the following section, and the alteration products themselves are described under the several mineral names.

Alteration.

The alteration of lithiophilite and the similar closely related minerals (triphylite and natrophilite), has yielded a large number of mineral species. Including all the occurrences known, not less than sixteen distinct species have been described as resulting from this alteration.[107] The following nine minerals, an secondary, have been identified in the altered lithiophilite from California.

1 . Palaite, a flesh-colored hydrous manganous phosphate, formula: 5 MnO·• 2P2O5 •·4H2O. Massive, non-pleochroic, probably monoclinic. It is derived from lithiophilite and alters to hureaulite.

2. Hureaulite, a brown hydrous manganous phosphate, differing in composition from palaite by the presence of an additional molecule of water; formula: 5 MnO •·2P2O5 •·5H2O. Pleochroism colorless, yellow, orange; monocline. It is derived from palaite and alters into (1) salmonsite or (2) a mixture of strengite and stewartite.

3. Salmonsite, a brown massive hydrous ferric manganous phosphate, formula: Fe2O3·• 9MnO •·4P2O5 •·14 H2O. Slightly pleochroic in yellow shades. Probably orthorhombic. It is derived from hureaulite and alters into (1) manganite or (2) strengite.

4. Strengite, hydrous ferric phosphate, formula: Fe2O3·P2O5·4H2O. Blue; pleochroism: colorless, blue, violet. Orthorhombic. Derived from (1) hureaulite, and (2) salmonsite.

5. Stewartite, a yellow hydrous manganous phosphate, composition not

[106] Lacroix, A. Mineralogie de la France, vol. 4, p. 365, 1910.

[107] In addition to the nine minerals found in California, the following are recorded by Lacroix (Mineralogie de la France, vol. 4); heterosite. dufrenite, pseutoheterosite, vilateite, cacoxenite, alluaudite, and unknown b.

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accurately known but probably with the formula: $3MnO \cdot P_2O_5 \cdot 4H_2O$. Triclinic, Pleochroism: colorless, very pale yellow, yellow. Derived from (I) lithiophilite and (2) hureaulite. Not known to alter into another mineral.

6. Sicklerite, a brown hydrous phosphate of ferric iron, manganous manganese and lithium, formula: $Fe_2O_3 \cdot 6MnO \cdot 4P_2O_5 \cdot 3(Li,H)_2O$. Pleochroism: yellow, brown. Probably orthorhombic. Derived from lithiophilite and alters to purpurite.

7. Purpurite, a purple hydrous manganic phosphate, formula: $Mn_2O_3 \cdot P_2O_5 \cdot H_2O$. Pleochroism: colorless, red, purple. Orthorhombic. Derived from the other minerals. Alters to manganite.

8. Manganite, a shining black hydrous manganic oxide, formula: $Mn_2O_3 \cdot H_2O$. Occurs massive and impure. Derived from and the final alteration product of the minerals already mentioned.

9. Psilomelane, a gray hydrous manganese oxide, formula: H_2MnO_5, considered as a manganate. A final alteration product of veins of palaite.

Alteration at Hiriart Hill. The lithiophilite from Hiriart Hill has altered to sicklerite. The alteration involves the oxidation of the iron, and the partial substitution of hydrogen (water) for lithium. The minerals palaite, hureaulite, salmonsite, stewartite, and strengite have not been identified on material from Hiriart Hill. It seems, therefore, that the alteration is a relatively simple one and as nearly fresh lithiophilite (material analyzed) has also been found at the same place, the alteration to sicklerite is a weathering process and due solely to the effect of the atmosphere and meteoric waters. The process of alteration can be expressed by means of the reaction:

$$2FeO \cdot 6MnO \cdot 4Li_2O + O \longrightarrow Fe_2O_3 \cdot 6MnO \cdot 3(Li,H)_2O \cdot P_2O_5 + Li_2O$$

Lithiophilite + oxygen $\longrightarrow$ sicklerite + lithia removed.
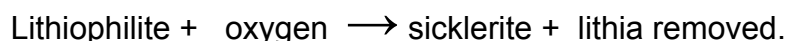
The structural formulas of the two minerals can be written so as to show their relation very well.

The sicklerite itself alters to purpurite and finally to manganite as described under sicklerite (p. 000).
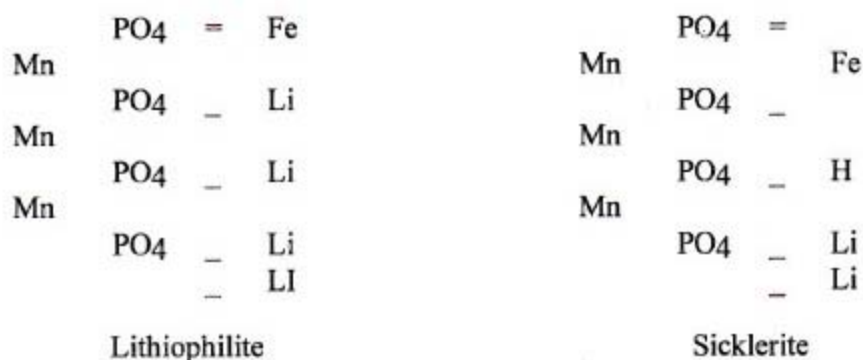
The reaction and formula given above are intended to show in a general way the manner of alteration and the general chemical changes that take place. The actual changes are much more complex and can probably not be expressed quantitatively by means of such a simple chemical equation. The sample of lithiophilite analyzed contained an appreciable amount of soda (Na_2O); however, sicklerite showed only a trace. If the original lithiophilite from which the sicklerite was formed contained a similar amount of soda, as seems reasonable to believe, then this soda has been replaced by

hydrogen while the lithia remained constant in amount. The analytical figures seem to bear out this view, as the molecular ratio of H2O is sicklerite in very nearly the same as that of Na2O in lithiophilite, lithia (Li2O) being taken as the same in both cases, as the following table shows.

The first alteration gas has genetically an entirely different history from the second, and as oxidizing influences (the air) were absent, the alteration must have been a magmatic one. In other words, the alteration of lithiophilite to palaite took place in the magma before the entire pegmatite mass had become a firm rock. The change may have been caused by the accumulation of much water near the

lithiophilite crystals; or, else, at lower temperatures, the two substances-- lithiophilite and water-- were not in stable equilibrium with one another and the reaction took place.

If the cleavages of the lithiophilite were sufficiently developed to admit of the entrance of solutions, stewartite was formed. If, however, the lithiophilite was a firm mass without cleavages, then palaite was formed. Why stewartite should be formed in one instance and palaite in another I do not know. But the occurrence of stewartite in fibrous veins and of palaite in granular masses is significant--although the correct interpretation of this phenomenon is very difficult, if at all feasible.

The structure of the fibrous veins of stewartite is so similar to that of serpentine in altering olivine, that it seems most reasonable to regard the change of lithiophilite to stewartite as taking place through the medium of solutions. Was the change of lithiophilite to palaite possibly caused by gases?

If the above explanations are correct, then the large lithiophilite crystals (at the time weathering agencies began to attack them) consisted either of unaltered lithiophilite and, palaite, or a mixture of lithiophilite and stewartite. Attacked by weathering agencies, the lithiophilite altered to sicklerite, and the· palaite to hureaulite, which in its turn was altered to other minerals. As erosion gradually brought the crystals nearer the Earth's surface, the weathering agencies became more abundant and one finds an increasing oxidation and increasing hydration as the alteration proceeds. The first change was from palaite to hureaulite, then from hureaulite to either salmonsite or a mixture of strengite and stewartite, and finally to either strengite or manganite. In correlation with these changes, there is an increasing amount of oxidation and of hydration. These facts are shown in the following table.

Effects of alteration of palaite.
--- means that the element not detected

Mineral	Percent	Percent	Percent	Percent	Percent	Percent
Palaite------	7.48	0.16	40.87	0.0 0	10.43	1.7 7
Hureaulite- Salmonsite	6.14 o.ooa	0.99	39.29	0.0 0	12.46	1.0 8
Stewartite b + strengite mixture-	3.84	9.53	37.74	0.0 0	15.30	1.0 6
Strengite---	0	2	20	U8	I7	---

a The 0.13 percent reported m the analysis of salmonsite belongs to the adm1xed palaite.

b The calculated composition of stewartite, based on the assumed formula given above and with the iron and manganese in the same ratio as in palaite, is FeO 7.67, MnO 41.94, P205 33.59, H20 16.80, Total l00.00. Stewartite (with above composition), and strengite are assumed to be mixed together in equal amounts.

The effects of the alteration are very clearly seen, the ferrous iron (FeO) is present in decreasing amounts corresponding to which the ferric iron, (Fei03) increases in amount. The same is true of the manganese. The water content shows a gradual increase. The percentage of lime becomes smaller with each stage of the alteration.

The final products of the alteration, purpurite and manganite, contain no ferrous or manganous constituent; they have become completely oxidized. Their water content is small, probably due to a readjustment with the permanent exposure to atmospheric weathering.

The changes that palaite has undergone are ascribed to weathering. Palaite, moreover, is in compact masses not fractured by cleavage or other cracks. Therefore, the changes due to alteration should proceed inward from the outside shell of each particular specimen and should show a concentric order of the minerals corresponding to the order given in the table just shown. Such is the case, as specimen containing several of these minerals show this concentric structure exceedingly well. The best specimen of this kind is shown in Plate XXVI C and diagrammatically in figure 63. The residual core of the flesh covered palaite is surrounded by brown hureaulite. In turn, the hureaulite is surrounded on three sides by brown salmonsite and on the fourth side by the stewartite-strengite mixture. Finally, black manganite surrounds the entire piece. A similar case, though not so complete is shown in Plate XXVI D, which shows a central core of hureaulite (dark) surrounded by a larger mass of salmonsite (light), which is surrounded on all sides by the black manganite.

Figure 63 Specimen showing concentric arrangement of alteration minerals of lithiophilite.

In as much as the fibrous veins of stewartite mentioned a few pages back are absent from such specimens that show the concentric alteration structure, it seems highly probably that the assumption made in regard to their genesis is correct and that they are due to magmatic alteration and not to weathering.

In several specimens, the alteration has been nearly complete, and the result is that the crystal is either completely changed to black manganite with here and there a small area of salmonsite, strengite, and other alteration products, or else a central remnant of these minerals is left. The large crystal illustrated in Plate XXVI A shows such a central remnant that is shown in more detail in Plate XXVI E.

Another phase of the alteration is the replacement of the palaite veins with salmonsite (as shown in Plate XXVI C and D) or in the mineral complex (as shown in Plate XXVI E) by manganite or psilomelane The final product is psilomelane. 'The replacement of such a palaite vein is shown in Plate XXVI D and diagrammatically in figures 65 and 66. The resultant veins in manganite is shown in Plate XXVI E.

Many of the specimens are a granular mixture of nearly all of these minerals and have a grayish- green color flecked with brown (hureaulite), yellow (salmonsite), blue (strengite), and red (purpurite). In these specimens alteration of various kinds and coming from various directions has taken place, and the result is an irregular granular mixture instead of an orderly arrangement of the various minerals. The network of stewartite veins has broken the residua' mass of lithiophilite and palaite into numerous separate cubes (or rectangles as seen in the thin sections). These have altered partially

or completely into one or more of all of these. minerals--brown sicklerite, brown hureaulite, yellow salmonsite, yellow stewartite, blue strengite, red purpurite, and black manganite. The result is a bewildering kaleidoscope of colors when such a section is revolved on the microscope stage.

Summary.

The alteration of lithiophilite has been described as proceeding in several ways dependent on whether the alteration was one of magmatic change or due to ordinary weathering processes. The magmatic alteration is accompanied by a substitution of hydrogen (water) for lithium and the addition of water. There is no oxidation of the iron or manganese. The alteration due to weathering is accompanied by an oxidation of the iron and manganese as well as by the addition of water.

The alteration can be briefly summarized in the accompanying diagram (fig. 64) showing the successive stages and whether they are caused by magmatic or by weathering influences.
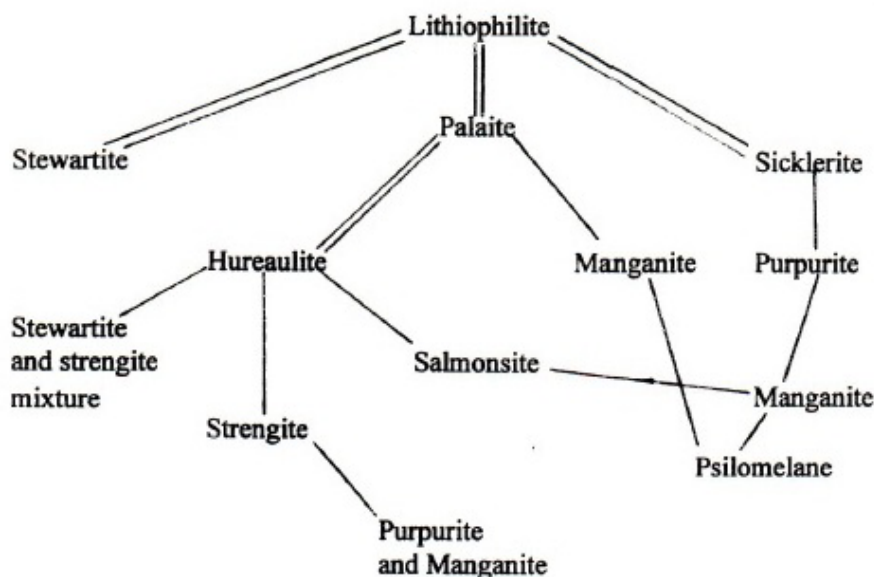
Figure 64 Alteration of lithiophilite from California. ‖ (double line) indicates magmatic alteration; │(single line) indicates weathering alterations and Queries (?) indicate method of formation could be evaluated.

Palaite

Occurrence.

Palaite,. a hydrous manganous phosphate with the formula $5MnO \cdot 2P_2O_5 \cdot 4H_2O$, has been found only in the west tunnel of the Stewart mine, at Pala, the locality after which the mineral was named.[108] 104 The mineral forms one of the complex that has resulted from the alteration of the large lithiophilite crystals as has just been described. It is there a secondary mineral. The associated minerals, likewise all secondary, are as follows: hureaulite, stewartite, salmonsite, strengite, sicklerite,

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•[108] Schaller, W. T. New manganese phosphates from the gem tourmaline field of Southern California. Jour. Washington Academy of Sciences, vol. 2, p. 143, 1912.

purpurite, manganite, psilomelane, and several other minerals of similar composition that could not be identified.

Forms.

Two forms of palaite were noted:
1. Massive.
a. Crystalline masses.
b. Narrow veins.
2.   Distinct crystals.

I. a) The mineral occurs as crystalline masses several centimeters thick that form the present nucleus of the altered lithiophilite crystals. Such a nucleus of palaite is shown in Plate XXVI F, which also shows the surrounding layers of other minerals into which palaite alters. Palaite is derived directly from lithiophilite, at least no intermediate mineral has been detected. By its own alteration it forms the minerals listed in the preceding paragraph. Scattered through the massive mineral are small particles of a pale yellow powdery substance, suggestive of uranium ocher but which qualitative tests failed to identify.

I.b. The narrow veins of palaite intersect the aggregate of secondary minerals, into which the lithiophilite has altered, in an irregular fashion. They do not follow the cleavage directions of the original lithiophilite but run in all directions. They are of fairly uniform diameter, averaging about 0.1 mm. Most of them are rather regular in their course and retain the same thickness throughout the slide. A few swell out in places and pinch together elsewhere. Some end suddenly or fork out into several veins. They are also faulted and intersect each other. Excepting for the intersection, their course reminds one very much of the courses of the pegmatite ledges as described in the first part of the report.

The veins are also found in massive salmonsite and are parallel to two rectangular cleavage directions, whereby they become much more regular in their course than those just described. The veins can be seen as minute lines in the photograph of a specimen of salmonsite shown in Plate XXVI E. The palaite in these veins is more fibrous than any other known occurrence of the mineral. This structure is well brought out Wider crossed nicols as is shown by Plate XXVI D. As the surrounding salmonsite is fresh and unaltered, there is no supply of black manganite to replace the palaite in the veins. Consequently, these appear clear and fresh and do not show the black inclusions shown in figure 65.

The palaite forming the veins grew from both sides and met in the center. This center line of contact of the two halves of the vein consists in many cases of brown hureaulite. The junction line is probably one of easiest across to oxidizing agents and therefore readily permits of the change of the palaite to hureaulite. Such a vein is shown in Plate XXVI s where the central band of brown hureaulite is plainly shown.

.Under crossed nicols, the palaite vein is seen to be formed of nearly rectangular blocks that do not all extinguish simultaneously and resemble the polysynthetic twinning of albite. I do not know whether they are individual crystal units, perhaps twinned, or whether the lines represent cleavages. The lines are not exactly normal to the sides of the vein but generally deviate only a small amount from perpendicularity. In a few cases, seen they were decidedly oblique. The mineral does not extinguish parallel to these lines. The blocks are seldom longer than wide (fig. 66) being generally shorter than the width of the vein. In some places the vein has a distinctly fibrous character. The fibrous character of the veins, illustrated in Plate XXVI

D, is especially characteristic when they are in salmonsite. Rarely, the veins consist of a fine-grained granular aggregate of irregular palaite grains. The identification of this vein mineral as palaite rests on qualitative analysis--the absence of lithium and abundance of water distinguishing it from lithiophilite. It was determined that all of its refractive indices were lower than 1.659, and the mineral could, therefore, not be colorless hureaulite. The lines traversing the veins are avenues of easy access for solutions, and the palaite bordering the lines is in many places altered or replaced by manganite.[109] Some manganite is doubtless also brought in from the neighboring altering manganese minerals, as in places a considerable mass of it has accumulated on the side of the vein and is gradually working its way into the vein itself. These lines of black psilomelane in the colorless palaite veins surrounded by various colored minerals form a very striking feature when viewed in thin section.

Figure 65 Pa!aite vein with central band of hureaulite. Shows several sketches of the manner in which the manganite occurs in these veins.

Figure 66 Sketches of manganite replacing palaite veins. Stewart mine, Pala. Enlarged about 2 times.

2. Distinct crystals. In the cavities of the crystalline masses are occasionally seen minute crystals showing one or two faces. The crystals are too minute and poorly developed for identification. It was determined that extinction is not parallel to their edges, and the mineral is tentatively referred to the monoclinic system.

No cleavage was noted in the thin sections of palaite. The density of the mineral averages about 3.17. The following are the results obtained. A small specimen containing both palaite and hureaulite gave a value of 3.19, and a second similar piece the value 3.182. These values were obtained by the Jolly balance. Small pieces of pure palaite, free from any hureaulite gave a minimum density of 3.14, as determined by means of Thoulet solution. The density of palaite is, therefore, taken as between 3.14 and 3.20.

The mineral is flesh-colored, being either nearly colorless or a very pale pink in some places. In thin section it is colorless and non-pleochroic. The lack of crystal outline makes it impossible to determine the. optical orientation.

The mean refractive index is about 1.656, slightly lower than that of hureaulite. The double refraction is low, about like that of the feldspars. From the thin section it is estimated as about 0.008.

Determined by the oil immersion method the refractive. indices are approximately as follows:

X = 1.652,
Y = 1.656, Z = 1.660,
Z-X = 0.008, n = 1.656

Chemical composition

Heated in a closed tube, palaite gives off considerable water without decrepitation but twins light gray or nearly white in color. Lithiophilite which palaite greatly resembles, decrepitates in a dosed tube and gives off only a trace of water. Palaite readily f!ies before the blowpipe giving a yellowish-green flame (due to

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[109] It is not known whether the product is manganite or psilomelane but is called the former for simplicity.

phosphorus) with no crimson; however, lithiophilite gives a strong crimson flame. On heating powdered palaite in a glass tube through which a current of dry air was passed, the following color changes were observed: The original color of the powder was a very light buff. On gentle heating a little water was given off (probably around 200°) without any color change. At a higher heat, the powder darkened and gave off much more water. The mineral is readily soluble in dilute acids.

The results of the chemical analyses are shown below and the ratios calculated from the average analysis are also given:

Chemical analyses and ratios of palaite, Stewart mine, Pala.
--- means no data.
W.T. Schaller, analyst.

Constituents	Samples					Average	Ratios	
	1	2	3	4	5			
FeO----------	7.50	7.59	7.56	---	---	7.48	0.1042	
MnO---------	40.86	40.88	---	---	---	40.87	.5764	$5.03 = 5 \times 1.01$
CaO----------	1.77	---	---	---	---	1.77	.0316	
Fe_2O_3--------	0.16	---	---	---	---	0.16	.0010	0.01 -------
P_2O_5---------	38.99	39.05	---	---	---	39.02	.2748	$1.94 = 2 \times 0.97$
H_2O (above 110°)	10.42	10.53	10.08	10.66	10.44	10.43	.5794	$4.09 = 4 \times 1.02$
$H_2O(110°)$--	none	–	–	–	–	none		
Li_2O---------	trace	–	–	–	–	trace		
Insoluble----	0.89	–	–	–	–	0.89		
Total----						100.62		

The first three values given for the water content were determined directly by igniting the mineral in a closed tube and then weighing the water in a part of the tube, as described by Penfield. The last two values were obtained by gently igniting the mineral until it just fused and determining the water by loss of weight. Quantitative experiments showed that no manganese was oxidized by such treatment; whereas, all the iron was changed to the ferric condition. The water content was determined five times in order to be sure of the result as the only difference in chemical composition between palaite and hureaulite is in the water content.

The ratios yield the formula 5MnO·2P2O5·4H2O, in which some of the manganese is replaced by iron and calcium. The ratio of iron plus calcium to manganese is about I : 5 and of iron to manganese plus calcium about I : 6. The mineral should, in conformity with the terminology previously advocated[110], be called an iron palaite or a ferrous palaite.

All of the water is given off above 100° as shown by the following table.

Loss of water from Palaite with heating

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[110] Schaller, W.T. A study of the rutile group: Bull. U.S. Geol. Survey No. 509, p. 38, 1912.

Temperature	Total loss of water, in percent
110°C--------	0.00
120°C--------	0.02
180°C--------	1.12
After ignition	10.66

The formula deduced from the analysis may be written: Mn2(MnOH)3H5(PO4)4, which may be structurally interpreted as follows:

$$
\begin{array}{ccc}
 & PO_4 & = & H_2 \\
Mn & & & \\
 & PO_4 & - & MnOH \\
Mn & & & \quad +H_2O \\
 & PO_4 & - & MnOH \\
Mn & & & \\
 & PO_4 & = & H_2
\end{array}
$$
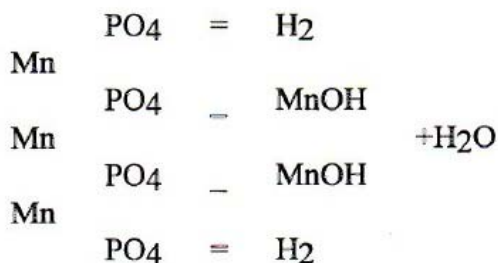
Such a structure formula is valuable for the suggestions it shows and for indicating the relationship to other minerals. Thus, the derivation of palaite 'from lithiophilite can be well shown by the use of such structural formulas, the relationship being as follows:

$$
\begin{array}{ccc}
 & PO_4 & = & Li_2 \\
Mn & & & \\
 & PO_4 & & \\
Mn & & & Mn \\
 & PO_4 & & \\
Mn & & & \\
 & PO_4 & = & Li_2 \\
 & \text{Lithiophilite}
\end{array}
\qquad
\begin{array}{ccc}
 & PO_4 & = & H_2 \\
Mn & & & \\
 & PO_4 & - & MnOH \\
Mn & & & \quad +H_2O \\
 & PO_4 & - & MnOH \\
Mn & & & \\
 & PO_4 & = & H_2 \\
 & \text{Palaite}
\end{array}
$$
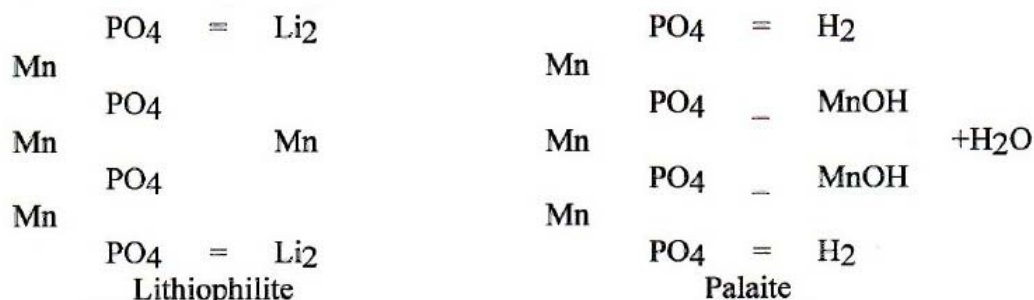
When heated, the groups (MnOH) and (FeOH) apparently first yield up their water and on further heating the five hydrogens are given off as water. This conclusion is based on the result observed on heating the mineral in a glass tube. Accordingly, the affinity of the (MnOH) groups should be less than that of the H, and in an alteration they should be the first to change. Palaite alters to hureaulite and the empirical chemical change consists only of the addition of one molecule of water. In the alteration of hureaulite, however, the hydroxyl group yield their water and the alteration takes place in the names just stated.

Hureaulite

Occurrence

The rare manganese phosphate hureaulite has previously been found at only

three localities. These are at Limoges, and at Chanteloube, France, and at Branchville, Connecticut. A doubtful occurrence at Michelsdorf, Silesia, Germany, is also cited by Dana in his System of Mineralogy. It has been artificially prepared by Erlenmeyer and Heinrich and also by de Schulten.[111] The mineral was collected in the Stewart mine at Pala, where it forms part of the large altered crystals of lithiophilite.

Forms.

The mineral was found in two distinct forms:
1. Massive.
2. Individual crystals.

1. Massive. The quantity of the minute individual crystals is exceedingly small so that practically all of the hureaulite is in the form of a massive brown mineral that is composed of a granular aggregate of small allotromorphic pieces. The massive mineral has resulted from the hydration and partial oxidation of palaite and not having recrystallized, has retained the shape of the palaite. The masses of hureaulite are several centimeters thick and many of them still have a central remnant of flesh-colored palaite. The mineral also forms a narrow seam in the center of the palaite veins, as already described and illustrated in Plate XXVI. It is also present in irregular small masses as a constituent of the mineral complex of which some of the altered lithiophilite crystals consist.

2. Individual crystals. Scattered over the surface of three specimens composed of palaite, hureaulite, and other unidentified minerals., were noticed minute colorless crystals, the largest of which is less than a millimeter long. The measurement of one of these crystals showed that they were identical with the published descriptions of hureaulite. They differ markedly however, from the massive form of hureaulite in both color and pleochroism. These minute crystals are colorless, nonpleochroic: the massive hureaulite is brown and strongly pleochroic. Minute, colorless crystals identical in form and properties with those of hureaulite, were also found in the loose granular mixture of these various secondary minerals. In addition to these colorless crystals, there were also noticed an abundance of microscopic brown crystals, strongly pleochroic like the massive mineral. The chemical analysis of the massive brown mineral showed nearly 1 percent of ferric iron, which is foreign to the mineral hureaulite--being a manganous phosphate. It seems, therefore, that the colorless crystals are a recrystallized, pure, hureaulite, probably free from any ferric iron; whereas, the brown pleochroic variety contains an appreciable amount of ferric iron, nearly 1 percent. In a few slides nearly all the hureaulite had changed to stewartite and other phosphates; the residual hureaulite was much more intensely colored and showed a more vivid pleochroism than the usual phase of the mineral. It seems as if by continued oxidation the amount of ferric iron increases, with corresponding stronger color, pleochroism and birefringence, until it reaches such an amount that the hureaulite is unable to retain it any longer, then the mineral breaks down into a mixture of strengite (a ferric phosphate) and stewartite (a manganous phosphate). This alteration of hureaulite is described in more detail on page 000.

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[111] B.S.M., 27, 123, 1904. De Schuten, A., Production artiftcielle de la hureaulite et de la hureaulite de cadmium: Bull. Soc. Franc. Mineralogie, vol. 27, 1904, p. 123.

Crystallography

Previous description.

The original description of hureaulite crystals was very unsatisfactory, and the crystallographical constants were first definitely determined by Dana on the material from Branchville, Connecticut. There still remained, however, a second type of violet crystals from France that could not be brought into accord with the Branchville crystals. These violet crystals have recently been shown by Lacroix[112] 108 to belong to a different mineral whose composition could not be determined but whose properties were very different to those of hureaulite. This new mineral was named vilateite. It has not been identified in the specimens from California.

A careful comparison of the published data on hureaulite with my own observations has indicated to me that there is a possibility that some of the colorless or nearly white hureaulite from France is in reality palaite. And yet the crystals of brown hureaulite (from France, for example figure 1 in Lacroix's description) are identical in form with the colorless crystals from Pala. So that at present it must remain unsettled whether any of the published descriptions of hureaulite should be referred to palaite.

Forms and angles.

The forms with the measured and calculated angles as determined on the Pala crystals are a follows, the orientation chosen being the one given by Goldschmidt in his Winkeltabellen, (p. 184 and 185).

Forms and angles, hureaulite, Pala.

No	Letter	Symbol	Measured		Calculated	
			ϕ	ρ	ϕ	ρ
1	a	100	90°00'	90°00'	90°00'	90°00'
2	m	110	27°57'	90°00'	27°39'	90°00'
3		011	22°34'	48°26'	22°58'	48°43'
4	ρ	$\overline{1}01$	90°05'	44°32'	90°00'	44°50'
5	f	101	90°25'	6°21'	90°00'	6°00'

The above chosen orientation, which has the crystallographical constants: a : b : c = 2.0889 : 1 : 1.0490, β = 66° 02', yields much simpler indices than the one originally given by Dana and is, therefore, to be preferred. The identification of the forms in the two orientations is to be seen in the following table.

Comparison of orientation of hureaulite.

[112] Lacroix, A., Mineralogie de la France, vol. 4, p. 477, 1910.

Goldschmidt		Dana	
a = 2.0889		a =	1.9192
c = 1.0490		c =	0.5245
β = 66°02'		=	84°01'
a	{100}	a	{100}
m	{110}	m	{110}
ε	{011}		{221}
	{101}		{401}
f	{101}	c	{001}

The letter of {001} Dana, {101} Goldschmidt, has been changed from c to f, otherwise the same letters have been retained for the forms. One of the faces of {001} was replaced by a large vicinal face, near to it in angular values.

```
calc. for {011}       = 22° 58',    = 48° 43'
Meas. for {011}     = 22° 29',    = 48° 23'
Meas. vicinal face   = 25° 11',    = 47° 24'
```

Habit.

The general appearance of the crystal is shown in figure 67. This differs from the figures given by Lacroix for hureaulite from la Vilate chiefly in the fact that the macropinacoid a {100} is smaller than the prism faces. The figures of the French crystals resemble more the microscopic crystals observed sketched in figure 67.

Figure 67 Colorless hureaulite, Stewart Mine, Pala. Forms: a {100} . m {110}, ε {011}, f' {ī01}, f {101}.

The orthopinacoid a {100} is narrow and vertically striated. The prism faces, m {110} vary in size, some being large, others narrow like a {100} . They are also vertically striated. The faces of ε {011} are in part striated parallel intersection of m and ε , and yield vicinal faces near to ε {011}. In the friable mixture of phosphates, colorless crystals of hureaulite were determined microscopically. They had the habit as shown in the accompanying figure 68.

Figure 68 Microscopic colorless crystals of hureaulite, Stewart mine, Pala. Forms: a {100}, m {1010} , ε{011}, {101}?. (Schaller note-3 drawings).

The crystals have low birefringence parallel extinction on the broad face (the macropinacoid) and an acute bisectrix with large axial angle that is normal to the large face, the axial plane being normal to the prism edge. There seemed to be evidences of a Cleavage parallel to the large face. These properties identify the crystals as hureaulite. The vertical direction was one of lesser velocity than parallel to the axial plane. From these facts, the optical orientation was determined as presently to be given. If the faces of ε {011} become very small or are entirely absent, the crystal receiving a rectangular outline as shown in figure 69 A; whereas, if the faces of c: {011} become as large as those of m {110} , then the crystals receive an octagonal shape as shown in

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figure 69 B. Both of these habits were observed only under the microscope.

Figure 69 Microscopic colorless crystals of hureaulite, Stewart mine, Pala. A. rectangular, B octagonal. Forms: a {100}, m {110}, ε {011}, f {101}.

All the crystals of hureaulite so far described are colorless. No measurable crystals of a brown color were found, but numerous microscopic ones of a brown color and strong pleochroism (orange, yellow, colorless) were observed. For instance, rectangular pieces (doubtless cleavage) were seen, similar in shape to those of figure 69 A. They possessed a similar optical orientation. The pleochroism is ny (c axis) = orange, nx (b axis) = yellow. Another crystal had the form shown in figure 69 B, the orientation being determined by the pleochroism, optical orientation and the angular measurements. The colored rectangular crystals are rare, a much more abundant phase consisting of rhombic crystals whose crystallographical orientation was again determined by the pleochroism, optical orientation, and angular measurements. Their appearance is shown in figure 70.

Figure 70 Microscopic, colored rhombic crystals of hureaulite, Stewart mine, Pala. (Schaller note--3 drawings).

Most of the rhombic crystals are uniform in structure and have the same pleochroism and extinction throughout. Others, however, are complex in their structure. For instance one crystal was observed that was divided into four parts by the diagonals of the rhombs. One opposite pair would be orange in color, while the second opposite pair would be yellow. The crystal is diagrammatically shown in figure 70. Examined under crossed nicols, it is seen that some of the apparently simple rhombic crystals have a complex structure. One crystal rhomb was divided into three separate fields optically, as shown in figure 70. Fields 1 and 2 extinguish together, fields 3 and 4 extinguish together, but not with 1 and 2, and field 5 does not extinguish at all, probably due to overlapping of l and 2 with 3 and 4. In many other rhombic plates the extinction is very irregular and undulating. The shape of these rhombic plates is very similar to those of stewartite, and, as one of the products of alteration of hureaulite is stewartite, it seems very probable that these undulating extinguishing rhombic plates of hureaulite are in an intermediate stage of transformation into stewartite.

Physical properties.

Hureaulite possesses a very good cleavage parallel to the orthopinacoid. Due to this cleavage, thin plates of known orientation can be obtained by crushing the crystals. The density of hureaulite is given by different authors as follows:

Author	Locality	Density
Damour	La Vilate	3.185
Damour	La Vilate	3.198
Wells	Connecticut	3.149
Lacroix	La Vilate	3.175
Lacroix	La Vilate	3.18

My own observations yielded the following results. By using small fragments and

the Thoulet solution, the maximum density was found to be 3.132, and the minimum density was found to be 3.070. These values are lower than those given for the French hureaulite, which, as just given, average about 3.18. Could the specimens on which these determinations were made possible be palaite? 1be density of the Branchvine mineral is intermediate between the two sets of values. The density of hureaulite is, therefore, given as 3.07 to 3.18, with an average value of about 3.12.

The color has already been described as brown; more accurately it is a dark venetian red to a dark burnt sienna.

Optical Properties.

The optical orientation as given in the literature is as follows: Axial plane normal to b {010}, the BX_0 approximately normal to a {100}. Negative.[113]. The microscopic colorless crystals have however, the acute bisectrix nearly normal to a {100}, the axial plane being normal to b {010} and nearly so to the vertical axis. The crystals are optically positive and the orientation is as follows.

    b axis, a parallel axis   = X
    Approximately parallel, c axis = Y
    Approximately parallel, a axis = Z

The inclination of the acute bisectrix to the a axis was not determined.

The pleochroism of the brown hureaulite is as follows:

Axis	Schaller determination	Lacroix's determination
X =	Colorless	Colorless
Y =	Yellow	Light yellow, with a slight rose tint
Z =	Venetian red or orange chrome	Reddish yellow to red brown

The refractive indices were determined to be about as follows, using the oil immersion method and the birefringence as determined on thin section of known thickness.

    (colo   1.6
    (yell   1.6   X- Z = 0.016
    (ora   1.6   Mean index (n) =
   nae)   72   1.663.

Lacroix gives the mean refractive index as 1.66.

Chemical composition.

In its pyrognostic properties, hureaulite resembles palaite. It has, in fact, nearly

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[113] Note that Dana's System of Mineralogy, Sixth edition, lists X = b, Y= a; and Z ∧ c= 75°, Biaxial negative.

identical composition containing only one molecule mote of water. The analysis made on the massive brown material, yielded the following results.

Analyses and ratios of brown hureaulite, Stewart mine, Pala.
W.T. Schaller, analyst.

Constituent	Sample					Average	Ratios	
	1.	2.	3.	4.	5.			
FeO-------	6.14	6.13	---	---	--	6.14	0.0855	
MnO------	38.39	40.44	40.19	38.45	39.00	39.29	.5542	$4.86 = 5 \times 0.97$
CaO-------	1.08	---				1.08	.0191	
P_2O_5------	38.63	---				38.63	.2720	$2.01 = 2 \times 1.01$
H_2O-------	12.34	12.58				12.46	.6922	$5.11 = 5 \times 1.02$
Fe_2O_3-----	.86	1.11	---	---	---	.99	.0062	0.05
Li_2O------	trace	---	---	---	---	trace		
Residue--	1.58	---	---	---	---	1.58		
Total-						100.17		

The values for manganese show considerable variation. This is due to the fact that hureaulite was the first mineral in which the MnO was determined by titration with potassium permanganate in an hydrofluoric acid solution, and sufficient practice had not been had at that time in accurately determining the end point of the titration.

The water is all given off above 100° C. The following values were obtained by heating the powdered mineral to the given temperatures.

Loss of water at different temperatures.

Temperature	Total loss of water, in percent
110°C-------	0.00
180°C-------	1.17
On ignition	12.30

The formula of hureaulite $5MnO \cdot 2P_2O_5 \cdot 5H_2O$ can be written structurally as follows.

$$
\begin{array}{ccc}
& PO_4 & = & H_2 \\
Mn & & & \\
& PO_4 & - & MnOH & + 2H_2O \\
Mn & & & \\
& PO_4 & - & MnOH \\
Mn & & & \\
& PO_4 & = & H_2
\end{array}
$$
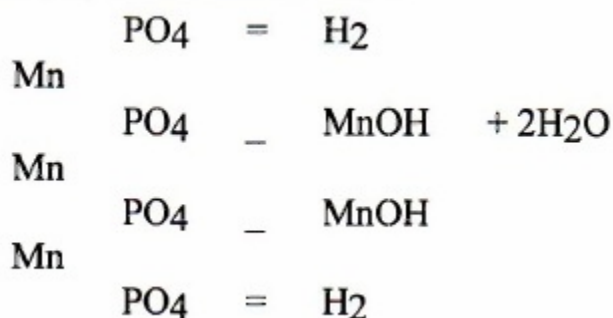
This form is very similar to that suggested for palaite. Considered by itself hureaulite may be treated as a pyrophosphate, being a manganese salt of the theoretically simplest phosphoric acid H_5PO_5.

The formula may then be written:

$$
\begin{array}{lll}
& PO_5 & H_4 \\
Mn & & \\
& PO_5 & H_3 \\
Mn & & \\
& PO_5 & H_3 \\
Mn & & \\
& PO_5 & Mn_2
\end{array}
$$
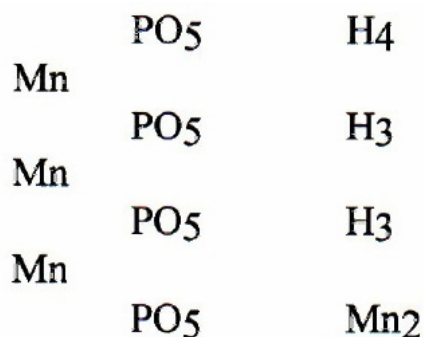
Such a formulation, however, would place hureaulite in a class by itself and utterly fails to show its chemical relation to the associated minerals, and particularly to those from which it is derived and into which it alters. The orthophosphate formula, which shows these relations very well, is, therefore, to be preferred. Hureaulite is derived from palaite, and the relation has already been described.

Hureaulite alters in two different ways· yielding either (1) salmonsite or (2) a mixture of stewartite and strengite. These relations can be well expressed chemically, as they consist of the complete oxidation of the ferrous iron in the hureaulite with the addition of water. Under certain conditions the mineral is able to preserve its integrity during this alteration and changes to a from mass of salmonsite. under other conditions the integrity of the mineral cannot be preserved, and the resultant product is a friable mixture of essentially stewartite and strengite.

The alteration to salmonsite can be approximately expressed by the following equation. It is to be noticed

$$2FeO \cdot 8MnO \cdot 4P_2O_5 \cdot 10\,H_2O + MnO + O + 4H_2O \rightarrow Fe_2O_3 \cdot 9MnO \cdot 4P_2O_5 \cdot 14H_2O$$

Hureaulite $\longrightarrow$ Salmonsite

It is to be noticed, however, that a small amount of manganese has to be added to the hureaulite. The iron and manganese (FeO + MnO) of hureaulite is insufficient to yield the necessary amount to form salmonsite (Fe2O3 + MnO). Where the formula of salmonsite to be written with 8 MnO instead of with 9 MnO, then the alteration would be a very simple one chemically. The analytical figures, however, yield very closely the ratio of 1 : 9 for Fe2O3 : MnO (see p. 000).

The change to the mixture of stewartite and strengite can not be definitely expressed chemically as the composition of stewartite is not known. The reaction should be comparable to the one yielding salmonsite, as both originate from the same mineral. This comparison is, in fact, made in order to arrive at the probable composition of stewartite (see p. 000).

Salmonsite.

Occurrence.

The mineral salmonsite, named[114] after A. Salmons, formerly of Pala (but now in San Diego), has been found only in the Stewart mine at Pala. Its presence was

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[114] Schaller, W.T. New manganese phosphates from the gem tourmaline field of southern California: Jour. Washington Academy of Sciences, vo12, p. 143, 1912

suggested in the powdered sample of lithiophilite from Hiriart Hill, Pala, but the identity of the mineral observed could not be confirmed. I did not see any specimens of the French phosphate that suggested the presence of salmonsite. The mineral is a secondary one, being derived from hureaulite.

Forms.

Massive salmonsite is the only found so far observed. It is present in masses reaching a maximum size of 5 cm; however, in most cases the masses of salmonsite are only 1 or rarely 2 cm thick. It also occurs in small and irregular masses throughout the massive complex of secondary phosphates. Though the mineral has been derived from the massive granular hureaulite, which shows no cleavage, the masses of salmonsite show fairly well developed cleavages that are at right angles to each other. In thin section the salmonsite is seen to be formed of a granular aggregate of minute particles, clearly indicating its secondary origin. The cleavages observed, therefore, do not belong to the salmonsite itself. They are moreover, not developed on all specimens and, where present, seem to be related to the original cleavages of the lithiophilite.

Some samples of salmonsite are nearly pure, as for example the band in the specimen illustrated in Plate XXVI. A little strengite and palaite is present, but its amount is very small. On other samples, the small masses of blue strengite are very abundant, some areas being sprinkled so abundantly with strengite as to appear almost blue. This is a phase of the alteration of the salmonsite. Another feature of the salmonsite is the abundance, in certain specimens of veins of fibrous palaite. These veins are generally parallel to the salmonsite cleavages and form a rectangular network. Veins of no oriental direction are also present, but they are of minor abundance. A number of specimens of salmonsite are reproduced on Plate XXVI.

Physical properties.

There are at least two distinct cleavages that are normal to each other. The cleavages are particularly noticeable, because in the specimens neither the hureaulite nor palaite, from which the salmonsite is derived, show any cleavage. Considered by itself the cleavage is not very good, and the faces are dull and somewhat uneven. The cleavage shows well in the thin section. The hardness of the mineral is about 4. The density is 2.88.

The color varies somewhat in tint. It is a light yellow ocher, pale raw sienna, or a brown pink. The luster is dull and earthy. The streak is a very pale yellowish white.

The optical properties are in harmony with orthorhombic symmetry. The extinction is parallel to the cleavage lines. The indices of refraction and the birefringence are about as follows, the values being determined by the oil immersion method.

$$X = 1.655$$
$$Y = 1.660 \qquad (X - Z) = 0.10$$
$$Z = 1.665$$

In thin section the mineral is transparent and of a pale yellow color. Pleochroism is hardly noticeable, a slight change in the yellowish tint being the only observed change. Examined under the highest magnification, a distinct pleochroism is noticeable, on some of the larger grains. The colors are colorless, yellow, pale Naples yellow.

Chemical Composition.

Salmonsite fuses readily and is easily soluble in acids. Abundant water is given off when heated in a closed tube. On being heated to 180° the mineral darkens and becomes still darker on ignition. The results of the chemical analysis are shown in the table below.

Analysis and ratios of salmonsite, Stewart mine, Pala.
- - - - - means element was not detected Analyst, W T Schaller

Constituent	Samples			Average	Ratios	
	1.	2.	3.			
FeO---------	none	none	0.13	0.13	0.0018	
MnO--------	37.98	37.50	---	37.74	.5323	$9.02 = 9 \times 1.00$
CaO---------	1.06	---	---	1.06	.0191	
Fe_2O_3-------	9.76	9.30	---	9.53	.0597	$0.98 = 1 \times 0.98$
P_2O_5--------	35.11	34.50	34.98	34.86	.2455	$4.01 = 4 \times 1.00$
H_2O---------	15.93	15.53	---	15.73	.8500	$14.28 = 14 \times 1.02$
Insoluble--	1.61	1.27	1.33	1.40		
Total---				100.45		

The first two small samples analyzed gave results which indicated that practically no ferrous iron, if in fact any at all, was present in the sample. A third determination, made on a larger sample slightly over a gram in weight, was titrated with a more dilute permanganate solution. The results indicated that about 0.13 percent of FeO was present; this figure represents, however, a maximum value. The presence of this FeO may be ascribed to the small amounts of palaite veins that were not separated from the sample analyzed. Palaite contains 7.48 percent FeO. Therefore, not more than 2 percent palaite was present in the sample analyzed. In the ratios, the pa1aite equivalent to 0.13 percent FeO has been deducted.

The formula derived from the ratios given in the table is Fe2O3 •·9MnO·• 4P2O5 •·14H2O. The formula is not a simple on, yet the material is homogeneous and sufficiently pure for a decisive determination of its composition.

The loss of water at different temperatures is as follows:

Loss of water at different temperatures for salmonsite,
Stewart mine, Pala.

Temperature	Total loss of water,
110°C	0.43
180°C	8.90
On ignition	15.53

Alteration.

The alteration of salmonsite proceeds in two ways. The simplest alteration is to manganite. This change requires the oxidation of the manganese (partial only if we consider manganite to have the formula MnO •·MnO2) and removal of most of the iron and phosphorus. This alteration is illustrated in Plate XXVI A, which shows a band of brown salmonsite between the brownish-red hureaulite and the outer shell of black manganite. It is nearly pure and represents the middle stage in the alteration hureaulite-salmonsite- manganite. The salmonsite in this specimen has altered directly to manganite with the production of very little strengite.

The second mode of alteration is more complex and its history may be described as taking place in three stages. The first stage is the change of the compact salmonsite into a shattered mass of salmonsite cleavage pieces. The mineral has become somewhat lighter in color and even more dull and earthy looking. The second stage shows a good deal of the salmonsite change to blue strengite. No other mineral has been observed mixed with the strengite, and it seems as if the manganese and some of the phosphoric acid has been removed. In consequence, the volume occupied by the strengite is considerably less than that occupied by the original salmonsite. These first two stages are very closely connected and in fact could almost be considered as forming together but a single stage (fig. 71).

Figure 71 Sketch of alteration of salmonsite, Stewart mine, Pala.

The process of alteration as far as described is well illustrated by the specimen shown in Plate XXVI E. In the upper left portion of the specimen is seen a small mass of brown salmonsite, which on its right side is breaking up into a shattered mass of cleaved mineral. A little more to the right is an abundance of blue strengite. In addition, the specimen also shows that a loss of material has taken place and the strengite occurs in a partial cavity. The original mass of salmonsite extended only so far.

To return to the further alteration of the mineral. The third stage consisted of the complete change of the salmonsite to strengite with the removal of the manganese and excess phosphoric acid. There is now not enough material to occupy all the space formerly taken up by the original salmonsite and the result is the production of a cavity, partially filled with strengite.

This third and last stage of the alteration is shown by the same specimen which illustrated the first two changes (Plate XXVI E). In the right hand comer is seen such a cavity in which only strengite is to be found. On the same plate are illustrated two other specimens (G and H) that show similar cavities containing strengite, the one (H) showing a cavity of considerable size. The cavity itself is not so well shown in has in G because the larger part of the specimen surrounding the complete cavity has been removed. Several grams of loose powdery strengite were poured out of this cavity. I have frequently broken into such small cavities containing loose strengite, while I was studying the various specimens.

In as much as the change of salmonsite to manganite produces no cavity; whereas, that of salmonsite to strengite does produce one, the question arises as to what becomes of the excess material produced by the change of salmonsite to manganite. Theoretically, the change can be expressed by the following reaction:

$$2[Fe_2O_3 \bullet 9MnO \bullet 4P_2O_5 \bullet 14H_2O] \longrightarrow 9[Mn_2O_3 \bullet H_2O] + 2[Fe_2O_3 \bullet P_2O_5 \bullet 4H_2O + nP_2O_5 \bullet H_2O]$$
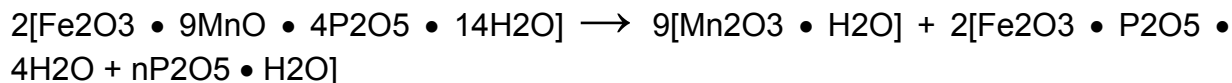
salmonsite $\longrightarrow$ manganite + strengite $\longrightarrow$ phosphoric acid and one would expect to find either small amounts of strengite or its final alteration product (limonite) mixed with the manganite. Such is not the case. No strengite or limonite was seen mixed with the manganite. If these have been removed one would expect to find the resultant manganite occupying a smaller volume and the consequent production of a cavity. The volume of the manganite is, however, very nearly the same as that of the original salmonsite. A chemical examination of the manganite showed that it contained small, but appreciable amounts, of both ferric iron and phosphoric acid. The excess material, as indicated by the reaction given above has, therefore, not been completely removed but has been partially taken up by the manganite. The formula of manganite, $Mn_2O_3 \cdot H_2O$ suggests that Fe_2O_3 may be chemically taken up by the mineral without its chemical structure being destroyed, and possibly some relation exists between manganates and phosphates. The excess material may of course also be considered as simply dissolved by the manganite. The condition of its occurrence is not of so great importance as the fact that this excess $Fe_2O_3 + P_2O_5$ has not been removed but remains in the final alteration product.

Stewartite.

Occurrence.

Stewartite was named[115] after the Stewart mine at Pala, which is the only locality in this tourmaline field in which it has been found. What is without doubt the same mineral has, however, been found also in France and has been partially described by Lacroix as commented on in the description of the mineral. Several specimens of the French "hureaulite," which were seen in various European collections contained well-developed crystals of stewartite, which it is hoped will be described.

Forms.

Stewartite occurs as small particles scattered through a complex aggregate of minerals containing, in addition, strengite, salmonsite, hureaulite, purpurite, manganite, and other manganese oxides. It forms either a firm matrix of massive yellow material,embedded in which are blue spherulites of strengite (illustrated in Plate XXVI F) or else it forms a loosely coherent powdery mass consisting of essentially the minerals just enumerated.
The mineral has been noticed in two distinct forms, each of which presents three phases.

1   Massive
a. Fibrous veins.
b. Fibrous fringes.
c. Solid masses which still show a certain degree of fibrosity.
2.   Distinct crystals.
a. Allotromorphic masses which consist of a single crystallized unit.
b. Needlelike crystals, approaching I b.
c. Complete crystals.

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[115] Lacroix, A. Mineralogie de la France, vol. 4, p. 506, 1 910.

1. a. fibrous veins. The original lithiophilite is seamed by minute cleavage forming two sets of lines perpendicular to one another. These minute cracks, about 00 mm. in thickness, are filled with fibrous stewartite, very similar to the way in which cleavage cracks in olivine are filled with fibrous serpentine. These minute veins of secondary stewartite generally have a drawn out lens shape; their sides are regular but not absolutely straight. The veins tend to pinch out at both extremities; reaching a maximum thickness in their center.

A section cut parallel to one of the cleavages of the original lithiophilite, has an appearance in regard to the fibrous stewartite veins, similar to the sketch shown in figure 72. Such an occurrence is also shown photographically in Plate XXVI C.

Figure 72 Veins of fibrous stewartite in palaite. Stewart mine, Pala.

In a few places in a section cut obliquely, .the 'lens have a more symmetrical shape as is sketched in figure 73, and shown in Plate XXVI D.

Figure 73 Symmetrical lenses of fibrous stewartite in palaite, Stewart mine, Pala.

In some instances the veins are so thick as to almost entirely replace the palaite, which thus becomes altered to a solid mass of nearly pure stewartite. Such an instance is shown in figure 74.

Figure 74 Compact mass of stewartite veins nearly completely replacing palaite, Stewart mine, Pala.

A section cut normal to the two cleavages shows two sets of veins normal to each other as shown in figure 75. The remaining palaite is cut up by these veins into minute rectangular blocks many of which have altered to some other mineral (hureaulite, strengite, stewartite, etc.). The fibers in these veins extend out from both sides, meeting in the center and forming a rather well defined straight median line, shown in the accompanying figures 75 and 76. This straight median line is seldom exactly in the middle. It is in places. discontinuous and displaced as shown in the largest lens of -figure 00. The fibers are not exactly normal to the width or to the edges of the vein but deviate slightly.

They are also not strictly parallel though nearly so. The lenses are bordered by a black line of total reflection due to the higher refractive index of the stewartite. A few of these fibrous veins had changed to a massive compact phase of the same mineral.

The fibers have oblique extinction. Pleochroism is marked; parallel to the elongation of the fibers (normal to the length of the veins), a very pale yellow, nearly colorless; normal to the elongation of the fibers a much deeper yellow but still not a strong yellow, regarding the color by itself. Absorption normal to the fibers greater than parallel to their elongation. Double refraction high, giving brilliant colors of the second order in the thinnest sections.

1. b. Fibrous fringes. Several instances were noted where bunches of radiating fibrous fringes grew out from the sides of the vein, extending into and gradually replacing the palaite between the veins. Such an example is shown in figure 75.

Figure 75 Fringe of fibrous stewartite replacing palaite; s, stewartite; p, palaite. Stewart mine, Pala.

Where this process has developed to a greater degree, nearly an of the palaite has changed to stewartite. Such an instance is shown in figure 76.

Figure 76 Fibrous stewartite replacing palaite; s, stewartite; p, palaite. Stewart mine, Pala.

The mineral has been noticed as fibers forming small brushes or as distinct veins. Some of the solid masses still show a certain degree of fibrosity. Distinct crystals were also found. Much of the original lithiophilite is seamed by minute cleavage cracks forming two sets of lines perpendicular to one another. These minute cracks, about 00 mm. in thickness, are filled with fibrous stewartite, very similar to the way in which cleavage cracks in olivine are filled with fibrous serpentine. These minute veins of secondary stewartite generally have a drawn out lens shape, reaching a maximum thickness in their center.

1. c. Solid masses which still show a certain degree of fibrosity. The fibrous veins of 1.a. and the fibrous fringes on 1.b. are in places changed to compact masses of the mineral which still show to a certain extent their original fibrous character. Thus, figure 77 shows a vein of originally fibrous stewartite now almost completely changed to pieces of compact mineral. Isolated pieces of compact stewartite formed from such fibrous fringes as are shown in figures are abundant throughout the lithiophilite. Such a piece is sketched in figure 77 B.

Figure 77 A. Vein of fibrous stewartite changed to a compact phase of the same mineral. B. A group of fibers changed to a compact mass. Stewart mine, Pala.

2. a. Distinct crystals, forming single crystallized units but not showing any crystal outline. This phase is but a continuation of the change indicated in l.c. where the fibers have united into a compact mass of material. In such pieces as are classified under 2.a., the fibrous appearance has entirely disappeared and the pieces of mineral behave optically like a broken fragment of a single crystal.

2. b. Needlelike crystals. Groups of minute crystals were observed a number of times. These crystals hardly more than large fibers in size, seem to be complete crystals, bounded by plane faces, but their size is so minute that this could not be determined. Their general appearance is shown in figure 78. The crystals have nearly parallel extinction, are slightly pleochroic in yellow shades and have a high birefringence. Their elongation is negative.

Figure 78 Needlelike crystals of stewartite, Stewart mine, Pala.

2. c. Complete crystals. Numerous well defined crystals of stewartite were observed under the microscope. They resemble the larger crystals seen in the European collections. Most of the crystals are elongated rhomb's'. They are all thin tabular to the orthopinacoid a {100}. Their optical character shows them to be triclinic. The appearance of the crystals is shown in figure 79, which represents a group of parallel tabular crystals as seen under the microscope.

Figure 79 Sketch of group of parallel; tabular stewartite crystals, Stewart mine, Pala.

The forms are a {100} the broad tabular face; b {010} a narrow face parallel to which the crystals show a good cleavage: m {110} a narrow prism and o {111} a narrow face, the only termination observed. The only angles measurable are b {010} ∧ o {111}, which is about 66° and a {100} ∧ o {111}, which is about 37°. The

orientation of the crystal can be seen by figure 80, which also shows the optical orientation as far as determined.

Figure 80 Diagrammatic sketch of stewartite crystal showing crystal forms and optical orientation. Forms: a {100}, b {010}, m {110} , o {111}.

The axial plane is nearly parallel to the intersection edge of a {100} and o {111}. Its inclination to this edge was measured as 12°. The negative acute bisectrix is nearly normal to a {100} and a biaxial interference figure is readily seen on these tabular crystals. The axial angle is very large, the dispersion strong. The pleochroism and its relation to the optical orientation is as follows:

X   colorless
Y   very pale yellow
Z   yellow.

On a {100}, Y (very pale yellow) has an extinction angle of about 36°.
On cleavage sections parallel to b {010}, an optic axis is obliquely normal. The extinction angle X (colorless) ∧ c axis, on a cleavage face, is about 56°. The appearance of cleavage plates of stewartite is shown in figure 81.

Figure 81 Cleavage plates of stewartite, Stewart mine, Pala.

A second form of crystals is in rhombic-shaped plates whose orientation could not be coordinated with the crystals just described. The rhombic angle is about 80° and they have the appearance shown in figure 82, which also gives the optical orientation.

Figure 82 A, Rhombic crystal of stewartite, Stewart mine, Pala. B, diagrammatic sketch of rhombic crystal showing optical orientation.

Physical Properties.

The mineral possesses one good cleavage parallel to which thin plates can be separated by crushing the material. The density, determined on minute fragments by Thoulet solution is 2.94. The color is pale yellow, and the crystals have a vitreous luster. The optical orientation has already been given; the crystals being triclinic, and as their form not known, it is impossible to definitely correlate the crystallographical and optical orientations. The pleochroism is distinct X, colorless; Y, very pale yellow; Z, yellow.
The absorption in the fibers is greatest normal, to their elongation. The double refraction is very high about 0.060. The indices of refraction have been approximately determined as follows by the method of oil immersion.

1. $\gamma - \alpha =$
1. $n = 1.66.$
1.

It has been already stated that stewartite occurs in France and is identical with Lacroix' unknown mineral A. He gives the following description of the French

stewartite.[116] The pleochroism is marked: nm = pale yellow; np =golden yellow. The density is 2.46. These crystals are associated with brown-red hureaulite. They either support it (underlie it) or cover it. They, themselves, sometimes carry tine needles of cacoxenite.

There exists also a variety in bright yellow fibers, sometimes diverging, which constitute with dark brown-red fibro-lamellar hureaulite and with spherulitic angelardite, crystalline masses generally enve1oped by dufrenite; the first three of these minerals are intimately mixed. It is also to be noted that his description of "unknown B" agrees perfectly with the crystals of stewartite. The pleochroism is somewhat different, however, and the density given, 2.46 (imprint for 2.96?) is much lower than that of stewartite.

Chemical Composition

Stewartite is abundant in the altered lithiophilite crystals, but it is so intermingled with the other minerals of similar composition that a pure sample of it, sufficient for quantitative analysis, could not be obtained. Stewartite has been formed in two ways: (1) by the alteration of lithiophilite forming the fibrous veins, etc. (2) by the alteration of hureaulite, which yields a mixture of strengite and stewartite. Inasmuch as lithiophilite changes to stewartite without the production of another mineral, similar to its change to palaite, it seems reasonable to suppose that stewartite is a hydrous manganous phosphate. The alteration of hureaulite to stewartite is always accompanied by the production of considerable strengite, a ferric phosphate. It is, therefore, probably true that what remains--manganous phosphate-- forms stewartite. On the basis of the above statements stewartite is considered a hydrous manganous phosphate, and its formula can be approximated by considering its derivation.

The alteration of lithiophilite to palaite took place by the substitution of water for lithium and the addition of manganese and water.

Now, if it is assumed that a similar change took place in the alteration of lithiophilite to stewartite (in the fibrous veins), the reaction may be written as follows:

$$6MnO \cdot 3Li_2O \cdot 3P_2O_5 + 8H_2O \rightarrow 6MnO \cdot 3P_2O_5 \cdot 8H_2O + 3Li_2O \cdot P_2O_5$$

Lithiophilite + (water)   Stewartite   + (removed in solution).

The alteration of hureaulite yields a mixture of stewartite and strengite. The hureaulite analyzed has approximately the formula $2FeO \cdot 13MnO \cdot 6P_2O_5 \cdot 15H_2O$. On alteration this yields a ferric phosphate (strengite) and stewartite. The reaction may be expressed as follows:

$$2FeO \cdot 13MnO \cdot 6P_2O_5 \cdot 15H_2O + O + 9H_2O \rightarrow Fe_2O_3 \cdot P_2O_5 \cdot 4H_2O + 13MnO \cdot 5P_2O_5 \cdot 20H_2O$$
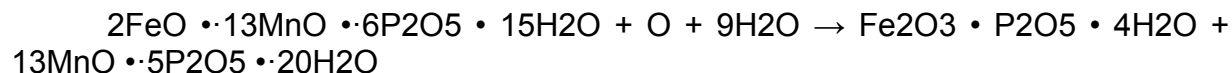
Hureaulite + (oxygen and water) alters to strengite +   stewartite.

The residue has the formula 5 1/5 MnO $\cdot$ $2P_2O_5 \cdot 8H_2O$, which with the addition of a little manganese would readily form as $6MnO \cdot 2P_2O_5 \cdot 8H_2O$. The formulas derived for stewartite from its modes of formation are close to $3MnO \cdot P_2O_5$

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[116] Lacroix, A. Mineralogie de la France, vol. 4, p. 506, 1910.

•·4H2O, which can also be written Mn3P2O5 •·4H2O, and this formula is, therefore, tentatively proposed for stewartite. This mineral would then fall into a natural group of minerals:

R3 P2O8· l/3 H2O   Fillowite.
R3 P2O8· 2 H2O   Fairfieldite, and others
R3 P2O8· 2-1/2 H2O   Messelite.
R3 P2O8· 3 H2O   Reddingite.
R3 P2O8· 4 H2O   Stewartite.
R3 P2O8· 5 H2O   Trichalcite.
R3 P2O8· 6 H2O   Picropharmacolite
R3 P2O8· 8 H2O   Vivianite, and others.

Structurally this formula can be interpreted as follows:

$$\begin{array}{c} \text{Mn} \\ \\ \text{Mn} \\ \\ \text{Mn} \end{array} \begin{array}{ccc} \text{PO}_4 & = & \text{H}_2 \\ \text{PO}_4 & - & \text{MnOH} \quad +2\text{H}_2\text{O} \\ \text{PO}_4 & - & \text{MnOH} \\ \text{PO}_4 & = & \text{H}_2 \end{array}$$
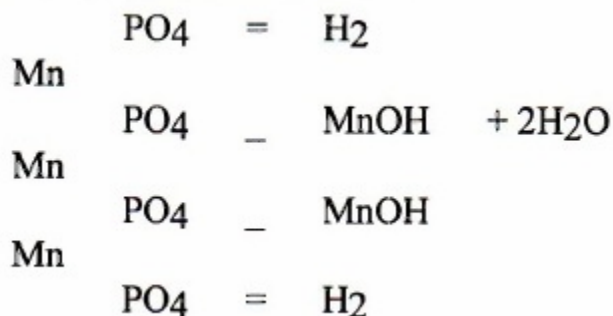
which shows its relations to the other minerals.

Strengite.

Occurrence.

Strengite is abundant in specimens of the altered lithiophilite crystals, though it has been definitely determined only in those from the Stewart mine at Pala. Strengite is a very rare mineral and has been found in only four general regions, in Germany near Giessen, in France at La Vilate, and in this county in Virginia and California. The characteristic color of strengite is in some shade of red or nearly colorless. The occurrences in France and California present the mineral in a blue color. The supposed vivianite, called angelardite by Lacroix,[117] is only a manganese variety of strengite.

Forms.

Strengite occurs in two distinct ways: (1) as a loose or rarely coherent powder, incompletely filling cavities in the altered lithiophilite, and (2) as isolated small crystalline masses scattered through the other secondary phosphates, especially stewartite. Its two modes of occurrences are directly related to its derivation. Where it has been derived from the alteration of salmonsite, it is found in the loose powdery form. Where it has formed by the alteration of hureaulite, it occurs as isolated crystalline masses. These two kinds of alteration have already been described.

The mineral presents itself in two distinct forms, each of which are subdivided

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[117] Lacroix, A. Mineralogie de la France, vol. 4, p. 522, 1910.

for descriptive purposes. The individual pieces are all small and were studied under the microscope by embedding pieces of the blue mineral in cooked Canada balsam.

These forms are

1. Irregular masses.

a.   Single crystal units not showing a complete and definite outline.

b.   Seaweed forms

c. Fibrous spherolites.

2.   Distinct crystals.

a.   Single crystals.

b.   Twinned crystals.

1. a. Irregular masses--single crystal units, not showing a complete and definite outline. Petrographically, the strengite masses here placed would be termed hypidiomorphic. They present nearly all gradations from an irregular mass not bounded by any straight edge to nearly complete crystals. All the pieces extinguish uniformly and are seen to consist of a single crystal unit. Many of the pieces show a well defined cleavage, as seen in figures 83 and 84. According to Dana's System of Mineralogy, strengite has an imperfect cleavage parallel to a {100}. The blue strengite here described shows two cleavages, which, however, have not been seen together on one piece. The appearance of these strengite masses is shown in figure 84. The pleochroism on these pieces is parallel to cleavage lines, violet; normal thereto, blue. Pieces of a very similar character but showing a much better crystal outline are parallel to the second cleavage and one shown in figure 83.

Figure 83 Strengite, cleavage pieces, showing violet-blue pleochroism.

Stewart mine, Pala.

Figure 84 Strengite, cleavage pieces normal to those shown in the preceding figure, and showing colorless-blue pleochroism. Stewart mine, Pala.

The pieces showing a violet-blue pleochroism are normal to a bisectrix, with a very large axial angle. The extinction on all these pieces is parallel and the birefringence moderate.

1. b. Seaweed forms. These forms are built up of fibrous sheaves, which are all inclined to each other. The pleochroism is in shades of violet, being generally a light violet red, or a reddish-violet parallel to the fibers and nearly colorless or a very pale violet normal thereto. Each of these masses being built up of numerous sheaves differently oriented, the reddish violet color shows in every position and the masses themselves, therefore, are a reddish violet. It is the presence of these red seaweed forms that causes some strengite specimens to have a distinct reddish hue. These forms are shown diagrammatically in figure 85.

Figure 85 Seaweed forms of strengite, Stewart mine, Pala.

1. e. Fibrous spherulites. The spherulitic form is a very common one for strengite, and all gradations can be observed from a nearly ideally symmetrical and complete spherulite to all forms of incomplete and distorted ones. Various forms of these spherulites are shown in figure 86. Some of the blue strengite has parasitic spherulitic bunches of the violet-red mineral as shown in figure 86.

Figure 86 Spherolitic forms of strengite, Stewart mine, Pala.

     2.a. Distinct crystals, single ones. Complete and single crystals were noted in two kinds: (I) square tablets, and (2) terminated crystals. The square tablets, shown in figure 87 A, show a violet- colorless pleochroism and parallel extinction. Very rarely, the comers are replaced by minute facets. The terminated crystals have a violet red to colorless pleochroism and are shown in figure 87 B. The crystals are so minute that the angle of the terminal faces could not well be measured.

     2.b. Twinned crystals. Whereas the square tablets are rare, twinned groups of these square tablets are much more abundant and consist either of two twinned crystals of two groups of parallel crystals twinned as the single couple or as a rosette of numerous repeated twins. These twinned crystals are shown in figure 88 C. In this figure 88 A represents a simple twin, which is explained by the diagram 88 B. The striations shown in 88 A are not cleavage lines. The twinning plane is {102} , the angle c {001} $\wedge$ {102} being 26°01', and the angle measured under the microscope 33°, 88 C and 88 D represent a group of parallel twinned crystals and 88 E shows a rosette of such twinned crystals. As the angle of twinning is about 60°, it takes six sectors to make an approximate complete cycle; a macroscopic crystal, twinned in such a way, would have a pseudohexagonal appearance.

Figure 87 Microscopic crystals of strengite, Stewart mine, Pala.

Figure 88 Twinned crystals of strengite, Stewart mine, Pala. A , simple twin; B, explanation of same; C, twinned group of parallel crystals; D, another phase of the same; E , a rosette of repeated twinning.

     Physical properties.

     The mineral shows two distinct cleavages probably normal to each other corresponding to two pinacoids. The density of the material could not well be determined on account of its fibrous nature. A value of 2.63 was obtained by means of Thoulet solution, but it is, doubtless, low on account of included air. The density of strengite is given in the textbooks as 2.87. The color of the California strengite is blue. The shade varies from a very pale blue to an intense blue. Rarely, the mineral has a violet red color due to the admixture of the seaweed forms, as already described. Very rarely, the strengite is a deep pink.

     Optically, the mineral agrees with the requirements of orthorhombic symmetry. With the lack of crystals of known orientation, the crystallographical and optical orientations can not be correlated. The pleochroism is very distinct and strong.

     X (c axis ?) = colorless
     Y (a axis ?) = violet
     Z (b axis?) = blue

     If the relation between X Y Z and the crystal axes is correct as given than the axial plane is parallel to a {100}, and the acute negative bisectrix is normal to c {001}. The difference in absorption between blue and violet is greater than that between violet and colorless. The absorption scheme is blue (Z) a violet (}) colorless (X).

     The refractive indices were approximately determined by oil immersion methods to be as follows:

α = 1.70-1.71

γ = 1.72-1.73 (γ- α) = 0.020.

Chemical Composition.

On being heated to 110° C, blue strengite suffers no change in color, at 180° C it becomes gray and on ignition it becomes light ash gray. It dissolves readily in HCl but not quickly in boiling dilute H_2SO_4 though it can all be brought into solution by H_2SO_4 if boiled long enough. The analysis is as follows:

Analysis and ratios of blue strengite, Stewart .Mine, Pala.
- - - - - - means no data. W.T. Schaller, analyst

Constituent oxides	Samples 1	2.	Average	Ratios	
FeO	none	none	- - - - -		
Fe2O3	41.03	41.24	41.14	0.2576	1.03 = 1 x 1.03
Mn2O3	2.31 a	2.41 b	2.36	0.0149	
CaO	0.44	0.23	0.34	0.0061	
P2O5	36.93	37.19	37.06	0.2610 0.98 = 1 x 0.98	
H2O	19.51	19.26	19.39 :	1.0583 3.98 = 4 x 0.99	
Insoluble---	- - - -	- - - - -	- - - - -		

a Titration with HF.
b Colorimetric.

The ratios yield the established formula Fe2O3 • P2O5 • 4H2O, which can be structurally interpreted in a form analogous to that suggested for the associated phosphates, namely

$$\begin{array}{cccc}
 & PO_4 & = & (FeOH) \\
(Fe\ OH) & & & \\
 & PO_4 & - & H \\
(Fe\ OH) & & & +4H_2O \\
 & PO_4 & - & H \\
(Fe\ OH) & & & \\
 & PO_4 & = & H
\end{array}$$
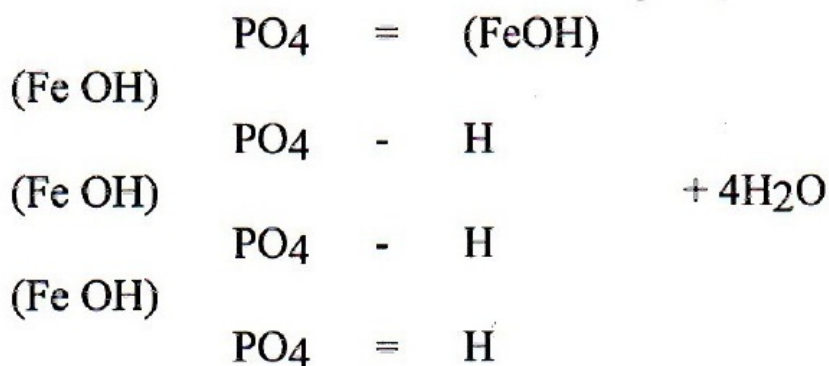
The loss of water was as follows:
Loss of water, strengite.

Temperature	Total loss of water, in percent

110°C------	0.16
120°C------	0.18
180"C------	17.87
On ignition	19.10

Strengite is not known to alter to another mineral, and nothing was seen to indicate any alteration in the blue strengite from California. It is one of the final products of the decomposition of the original lithiophilite. The identification of angelardite with strengite is based on the comparison of the properties given below. Lacroix's description of angelardite is as follows:

By tabulating the essential properties of angelardite and the blue strengite from California their identity is seen.

	Angelardite from France	Blue strengite, from California	
Density	2.77	2.63	
Mean refractive index--	1.70 (approx.)	1.71	
Pleochroism-	X = colorless	X= colorless	
	Y = light violet	Y= violet	
	Z= dark blue	Z= blue	
Birefringence-	much less than that of vivianite (0.05)	(0.02)	
Composition			
Fe2O3	58.7	43.5	
P2O5	25.8	37.1	
H2O	15.5	19.3	
Total	100.0	99.9	

The analysis of angelardite given by Lacroix and made by Berthier in 1826 is practically worthless. The association for and properties of the two minerals from France and from California are so similar that there is no question as to their identity.

Sicklerite.

Occurrence.

Sicklerite, named[118] after the Sickler family residing in Pala at the time of my visits, has been found in large pieces on Hiriart Hill, Pala, and has been identified in thin sections of material from the Stewart mine, Pala. On Hiriart Hill it was found as massive pieces reaching a maximum diameter of about 7 cm. The dark brown masses have resulted from the alteration of triphylite and retain the form of the

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[118] Schaller, W.T. New manganese phosphates from the gem tourmaline field of southern California: Journal of the Washington Academy of Sciences, vol. 2, p. 143, 1912.

original mineral. The mineral is probably very similar to Lacroix's pseudoheterosite [119] as well as to the brownish-black mineral[120] associated with purpurite from North Carolina.

Physical Properties.

The mineral has at least two cleavages, one of which is better developed than the other. The cleavages are normal to each other and show prominently in thin sections. They may be the cleavages of the original triphylite, though, more probably, they belong to the sicklerite. The mineral is brittle and has a hardness of about 4. The density was determined on different specimens by means of a Jolly balance. The average value obtained is 3.45. The different readings gave 3.477, 3.417, 3.453, 3.480, 3.446.

The color is a dark brown or a warm sepia and is mottled with minute specks of a dark red. The luster is somewhat greasy. The streak is a light bro• n, very closely resembling the color of salmonsite.

Optically, the mineral shows parallel extinction. The birefringence is moderate. The lowest index is slightly less than 1.736 and the other two are both higher. The approximate values are therefore:

$$\alpha = 1.730 \qquad \gamma = 1.75 \qquad \alpha - \gamma = 0.020 .$$

In thin section the mineral is a strong brown yellow, with a very marked pleochroism as follows:

X = oriental yellow.
Y = neutral orange or orange chrome.
Z = yellow orange (hureaulite is more of a reddish orange.)

The absorption of $Z > Y > X$.

Chemical composition.

The mineral fuses readily giving a crimson lithium flame along with the green due to the phosphoric acid.. It is easily soluble in acids. Heated in a closed tube, it does not decrepitate and yields only a trace of water. The analysis yielded the following results.

Analysis and ratios of sicklerite, Hiriart Hill, Pala.
- - - -- means not detected. W.T. Schaller, analyst.

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[119] Lacroix, A., Mineralogie de la France, vol. 4, p. 469, 1910.
[120] 116 Graton, L. C. and Schaller, W. T., Purpurite, a new mineral: Am. Jour, Sci., 4th series, vol. 20, p. 146, 1905.

Constituent	Sample			Average	Ratios
	1.	2.	3.		
FeO---------	none	none	---	---	---
MnO--------	33.62	33.67	33.51	33.60	$6.10 = 6 \times 1.02$
CaO---------	0.20	---	---	0.20	---
Fe_2O_3-------	11.46	11.06	---	11.26	---
Mn_2O_3------	2.10	---	---	2.10	$1.07 = 1 \times 1.07$
P_2O_5--------	42.87	43.33	---	43.10	$3.88 = 4 \times 0.97$
Li_2O--------	3.60	3.99	---	3.80	$2.83 = 3 \times 0.94$
H_2O---------	1.98[a]	1.35[b]	1.81	1.71	
Insoluble--	4.15	4.21		4.18	
Total---				99.95	

a Determined by loss on ignition: powder fused to brown mass.
b Determined directly.

The ratios obtained from the analysis lead to the formula 6MnO • 1Fe2O3 • 4P2O5 • 3(H2,Li2)O in which the Li2O is to H2O as 4 : 3. Considering the (H2,Li2) as composed entirely of (Li2) for convenience, the formula of sicklerite may be written: Mn3FeLi3P4O16, which may be structurally interpreted in a way as to show it close relations and derivation from lithiophilite.

```
        Li                                  Li
    PO4                                 PO4
        Li                                  Li
Mn                                  Mn
    PO4                                 PO4
Mn                  Fe              Mn                  Fe
    PO4                                 PO4
Mn                                  Mn
        Li                                  
    PO4                                 PO4   Li
        Li
```

Lithiophilite (Fe:Mn = 1:3)   Sicklerite
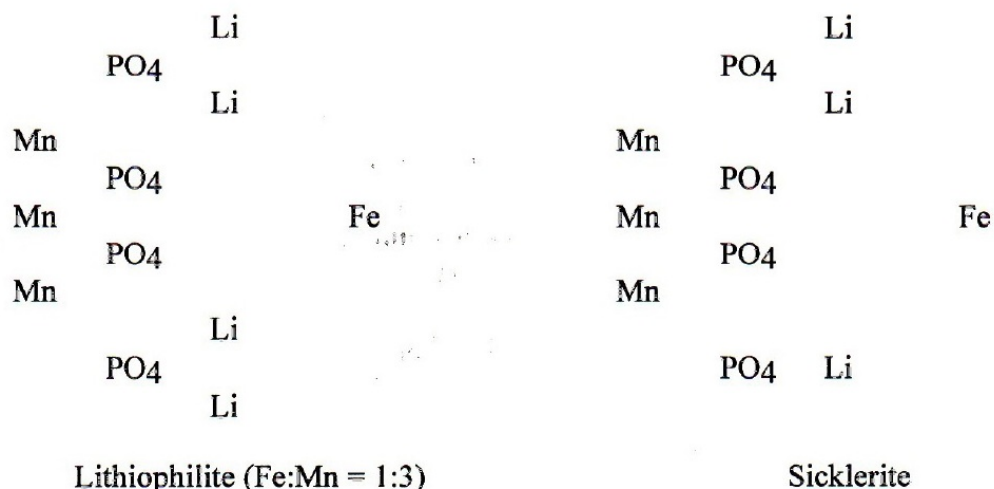
The alteration of lithiophilite to sicklerite is chemically a very simple one; it consists of the oxidation of the ferrous iron and the replacement thereby of one part of Li. The change has actually gone further in that some additional Li has been replaced by H.

Sicklerite alters to purpurite. No intermediate stage in the alteration has been observed though such may well be present. One specimen of apparently homogeneous material gave a yellow-brown streak (sicklerite) at one end and a purple streak (purpurite) at the other.

Purpurite.

Occurrence.

The mineral purpurite was first described[121] in 1905 identified by Lacroix[122] with the previously described heterosite, I proposed[123] to restrict the name heterosite to the ferric phosphate and the name purpurite to the manganic phosphate. Adopting also the suggestions made as to nomenclature[124], the various occurrences of purpurite and heterosite can be definitely defined as follows:

Nomenclature of purpurite- heterosite series.

Name	Composition	Locality
Purpurite	Mn2O3 •·P2O5 •·H2O	Not yet found pure
Ferric purpurite	(Mn,Fe)2O3 •·P2O5 •·H2O Mn>Fe	California and North Carolina
Manganic heterosite	(Fe,Mn)2O3 •·P205·• H2O Fe> Mn	France, Connecticut and South Dakota
Heterosite	Fe2O3 •·P2O5 •·H2O	Not yet found pure.

The California mineral has not been found in a condition suitable for chemical analysis and its determination as a ferric purpurite is therefore not proven; it may possibly be heterosite instead. But the general preponderance of the presence of manganese at the California localities suggests that purpurite is more probably correct than heterosite.

Purpurite has been found on many of the specimens. It was first identified on those from Hiriart Hill and is also present in the complex of altered minerals coming from the Stewart mine, at Pala. At the latter locality, it has been identified only in thin section, though it is better developed in these sections than in its more massive occurrence on Hiriart Hill.

Physical properties.

The properties of the mineral are in agreement with those determined on the original material. They could not be more completely determined as the California mineral is not better developed. The mineral gives parallel extinction and seems to be orthorhombic. The pleochroism is very striking and in harmony with that given by Lacroix for heterosite.

Purpurite California	Heterosite France

[121] Graton, L.C., and Schaller, W.T., Purpurite, a new mineral: Am. Jour. Sci., 4th series, vol. 20, p. 146, 1905.

[122] Lacroix, A., Mineralogie de la France, voL 4, p. 469, 1910

[123] Schaller, W.T., Mineralogical Notes, Series I , (Notes on purpurite and heterosite): U. S. Geological Survey Bull. 490, p. 72, 1911.

[124] Schaller, W. T., A study of the rutile group: U.S. Geol. Survey Bull. 509, p. 38, 1912.

nX = Dark, brownish gray	Gray, brown, reddish brown.
nY = Scarlet	Brilliant carmine.
nZ = Purple	Dark violet.

Purpurite does not seem to be a common alteration product of the minerals in the Stewart mine. The salmonsite, stewartite, and other phosphates, apparently alter directly to manganite without the formation of any intermediate purpurite. Sicklerite, however, seems to alter directly only to purpurite, as the specimens and thin sections from both Hiriart Hill show.

Orthoclase

The properties of orthoclase and microcline are so nearly identical, as recently emphasized by Zambonini[125] that the two minerals can hardly be considered as distinct. The essential microscopic difference is the cross-grating structure of microcline. On the basis of this test, some of the potash feldspar in both the upper and the lower parts of the pegmatite have been identified as orthoclase, but it was not possible, similarly, to distinguish the well-developed feldspar crystals occurring in the middle part. As most of these show the cross-grating structure, they have all been referred to microcline.

Microcline

Occurrence.

Potash feldspar is an essential component of any pegmatite, and no specific localities need, therefore, be given. Well-developed crystals have been found in most of the gem deposits, but they are particularly good and abundant in the different mines on Hiriart Hill, at Rincon, and at Mesa Grande.
The crystals of microcline are nearly all free from any enclosed mineral. Practically all of it, however, contains perthitically intergrown albite. A fine example of such perthitic intergrowth is shown by the feldspar from Rincon (Plate XXVII A) In other feldspars, notably those from Mesa Grande, the perthitic structure is not so well developed, and some of the feldspar seems to be nearly pure microcline. The large feldspars from this locality show very well a second generation of the same material. Such a specimen is shown Plate XXVII B where the broken surface is approximately parallel to a {100}. The inside square (darker in the photograph) has been partly dissolved and has left a rectangular network of plates parallel to c {001} and b {010}, respectively. These layers consist of microcline and some perthitic albite. At some places the inner wall consists of an albite lamella surrounded by the microcline. This inner square is free from any mineral inclusions.

PLATE XXVII. Feldspars.
A.   Perthite from Rincon; Crystal of perthite, an intergrowth of albite and microcline, from Rincon. Natural size. The crystal is a Baveno twin and the face shown is b {010}. See page 000.

[125] Zambonini, F., The morphotropic relations between enstatite, diopside, hedenbergite, aegirine, and spodumene: Zeitsch. Kryst. Mineral., vol. 46, p. 6, 1909.

B. Microcline crystal, broken approximately parallel to a {100}. Himalaya mine, Mesa Grande. Natural size. It shows a second generation of feldspar around a first, partly dissolved generation. The first generation shows a prominent rectangular network of albite plates parallel to c {001} and b {010}, respectively. It is free from any enclosed minerals. The second generation does not show the rectangular network so prominently and contains enclosed and partly embedded minerals: A, albite; L, lepidolite; Q, quartz; R, rubellite. described on page 000.

C. Microcline and albite (with topaz). Little Three mine, Ramona. Natural size. The albite is perched on the large microcline crystal and with the topaz is distinctly of a later formation.

The specimens illustrated were collected by the writer and are not in the United States National Museum.

The second generation of feldspar has formed a shell nearly a centimeter thick around the inner nucleus. This outer shell is not perthite and is in continuous orientation with the surrounded inner square. This outer shell contains abundant inclusions, generally only partly embedded, of albite (A), lepidolite (L), quartz (Q), and rubellite (pink tourmaline) (R), as shown in Plate XXVII B. The influence of these other minerals seems to have had a detrimental effect on the continuation of the growth of the feldspar similar to their effect on quartz as described on page 000. The outer layer of feldspar never grew very thick and seldom was able to completely enclose the albite, tourmaline, and lepidolite crystals. As a later alteration phase, solutions (probably meteoric) have penetrated the crystal along its cleavage cracks and continued the process of decay of the entire crystal. Where this has proceeded so far as to alter the feldspar completely, the partly enclosed gem tourmaline is freed and forms, with its associates, valuable components of a so- called pocket in the ledge. Such gem stones are easily freed from any matrix and, as they seldom are much cracked or broken, are more valuable than those embedded in solid rock.

A feldspar from Rincon (Plate XXVII B) shows a similar phase of alteration and has left a series of rectangular walls standing, which at places have become roofed over with a later layer of clear glassy feldspar.

Where this process of solution and decay has been succeeded by one of growth, a very interesting result is obtained. The specimen shown in Plate XXVIII C. from the San Diego mine, at Mesa Grande, has the form of a potash feldspar, the face shown in the photograph being b {010}, with c {001} and x {101}. The combination and habit of the crystal is shown in figure 89. Although the crystal is typically a potash feldspar in form, at present it consists of numerous albite crystals joined together in parallel position as shown in Plate XXVIII C. The combination on the albite crystals is c {001}, b {010}, m {110} and m' {$\bar{1}$10}, the individual crystals having the habit shown in figure 90.

Figure 89 Habit of feldspar crystal, San Diego mine, Mesa Grande.

Figure 90 Habit of albite crystals forming feldspar crystal.

The most reasonable explanation to offer for this feldspar is that it originally was a perthitic microcline in which the potash feldspar was dissolved away, leaving the walls of albite lamellae standing. Later, an accretion of material allowed these albite lamellae to grow and develop into the individual crystals now seen.

Some of the large potash feldspar crystals contain inclusions of quartz crystals, but they are very rare. Except for these quartzes, the formation of microcline

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antedated that of muscovite, lepidolite, albite, (excepting the perthitic albite), and the red tourmalines. It is very common to find a number of well- developed tabular albite crystals perched on the microcline, as shown in Plate XXVII C. The well- crystallized albite is certainly later in formation than the well-crystallized microcline.

Crystallography.

The crystals of microcline become very large though. At Ramona individual crystals several feet long have been found, and crystals about a foot long are abundant at many of the mines. The crystals are translucent, to opaque, or partly kaolinized.

The forms and combinations of the crystals are simple. A common habit is the one shown in figure 89, with the forms, c {001}, b {010}, m {110}, x {101}. The forms y {201}, z {130}, and o {111} are also present on many specimens. A rarer habit is one tabular to the base. Two such crystals from Hiriart Hill, at Pa[a, are shown in figures 91 and 92, the later showing an unusual habit due to the absence of the unit prism and the presence of the form z{130} as large faces.

Figure 91 Tabular microcline crystal, Hiriart Hill , Pala. Forms: c {001}, b {010}, z {130}, m {110}, x {101}.

Figure 92 Tabular, pointed microcline crystal, Hiriart Hill, Pala. Forms: c {001}, b {010}, z {130}.

Twin crystals are common. Many of the large feldspars from Mesa Grande are Carlsbad twins; many fine examples of perthite (Plate XXVII A) from the Mack mine at Rincon are Baveno twins.

Albite

Occurrence.

Albite is very abundantly developed throughout all of the pegmatites, and an enumeration of its localities is, therefore, superfluous. Nearly all the developed mines have yielded very fine specimens of albite crystals. (See Plates XXVII C, and XXVIII A).

As a rock-forming mineral, albite is abundant in the lower and upper parts of the pegmatites and has already been described as such. In the middle part of the pegmatites, albite occurs both intergrown with microcline to form perthite (Plate XXVII A) and as well-developed crystals (Plate XXVIII A). The directly associated minerals of the albite crystals are quartz, muscovite, lepidolite, red and green tourmalines, and beryl With these, it is contemporaneous in time of formation. The minerals topaz and spessartite are, at places, also contemporaneous, but, generally, they have formed later than the albite.

Albite occurs throughout the pegmatite as a rock-forming mineral, in the upper and lower parts of the pegmatite; as an intergrowth with microcline to form perthite; and as crystals associated with tourmaline, lepidolite, and quartz, in the middle part.

Crystallography.

The crystals of albite are very well developed in the tourmaline field, many
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specimens being well adapted for goniometric measurements. The size of the crystals varies from minute ones to those several centimeters in length. A few of the crystals are simple, but the vast majority are twinned often repeatedly after the albite law. Rogers[126] says of the albite twins from Rincon: The crystals are invariably twinned, usually according to both the albite and Carlsbad laws. A single albite twin and a single Carlsbad twin were observed. The compound twins are of two kinds: (1) Two halves of a crystal are twinned according to the Carlsbad law and each of these has polysynthetic twins according to the albite law; (2) an albite twin has a small crystal tacked on one side and united according to the Carlsbad law.

Most of the crystals examined by the writer are twinned only according to the albite law. The forms observed on these crystals are: b {010}, c {001}, m {110}, M {1l0}, z {130}, Z (p 30), x {101}, y {201}, o {111}, and u {111}.

The crystals are very uniformly of one habit-tabular parallel to the clinopinacoid b{010}. The faces of the three zones from b {010}, namely to the prisms, the base, and the orthodomes, are in many cases equally developed, so that the crystals have a hexagonal appearance. The general habit of these crystals is shown in figure 93.

Figure 93 General habit of albite crystals. Forms: b {010}, c {001}, m {110}, M {fx0}, z {130}, Z {130}, x {101}, y {201}. Rarer modifications of this habit are seen in a few specimens and are shown in figure 94.

Figure 94 Modiflcations of general habit, albite.

Frequently a repeated growth of forms or a grouping of several crystals in parallel position yields fernlike fringe of albite, is shown in figure 95.

Figure 95 Fernlike fringe of albite crystals.

PLATE XXVIII. Feldspars, garnet, spodumene, and topaz. from various localities.

A. Albite crystals, Little Three mine, Ramona. Natural size. The crystals are of the usual cleavelandite variety--thin tabular crystals, flattened parallel to b {010}. The photograph is an end view of a group of such crystals. The lower part of the specimen is a solid mass of albite.

B. Perthite from Rincon showing alteration by the removal of the microcline leaving a rectangular network of albite ridges. These have been partly roofed over by a later deposition of microcline. Enlarged two times.

C. Albite crystals in the form of microcline. San Diego mine, Mesa Grande. Natural size. The microcline of the original perthite crystal has been removed and the remaining albite lamellae have grown to well-developed parallel crystals. Described on page 000.

D. Spessartite garnets on schorlite (black tourmaline) Ramona. Natural size. In the collection of Col. W. A. Roebling, of Trenton, N.J. See page 000.

E. Spodumene, variety kunzite, in a cookeite matrix. Natural size. Mack mine, Rincon. In the collection of the American Museum of Natural History, New York City. See page 000.

F. Topaz crystal from the Little Three mine, Ramona. Natural size. Pale

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[126] Rogers, A.F., Minerals from the pegmatite veins of Rincon, San Diego County, California: School of Mines Quarterly, vol. 31, p. 210, 1910.

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bluish-clear to colorless, transparent. It was temporarily coated with ammonium chloride for photographic purposes. The brachypinacoid b {010} is placed in front, the larger triangular domes being faces of the form y {011}.The attached crystals are albite. See page 000.

G. Topaz crystals partly embedded in green tourmaline, Little Three mine, Ramona. Naturalize. The other crystals are albite. See page 000. The specimens shown in A, B, C, F, and G were collected by the writer and are now in the United States National Museum.

Garnet group

General description.

Among the species of the garnet group the following represent the best known:

Grossularite .... $3CaO \cdot Al_2O_3 \cdot 3SiO_2$.
Pyrope................. $3MgO \cdot Al_2O_3 \cdot 3SiO_2$..
Almandite .... $3FeO \cdot Al_2O_3 \cdot 3SiO_2$.
Spessartite........... $3MnO \cdot Al_2O_3 \cdot 3SiO_2$.
Andradite............ $3CaO \cdot Fe_2O_3 \cdot 3SiO_2$.

Very rarely are these found in a state approximating to the composition expressed by the above formulas. Much more commonly isomorphous mixtures of two or more of the above-named species occur, and it is sometimes much more convenient to use the group name "garnet" for a given specimen than to try to label it definitely according to species name. This would require a chemical analysis for each case, which would seldom be warranted.

Localities.

Garnets are common and abundant in the southern California pegmatites. Both the lithium-free pegmatites and those containing an abundance of lithium minerals carry large numbers of garnets. In the ordinary pegmatites, devoid of any special mineralogical interest, garnets are scattered promiscuously throughout the rock. In the unsymmetrical type of pegmatites, garnets are very abundant in the lower part and relatively scarce in the upper and middle parts.

The pay shoot contains but very few garnets, although in some places, as at Ramona, they are well developed and yield handsome gems and specimens. Nearly all the garnets contain appreciable amounts of manganese, and they are all tentatively classed as spessartites--future chemical work may show other species to be present

Almandite

The almandite species of garnet is found in nearly all the pegmatites in southern California but, generally, only in very small amount. Many of the garnets occurring in the lithium-bearing pegmatites are almandite, although at many places in the dikes spessartite is more abundant The crystals of almandite general1y show either the forms d {110} or n {211}, either above or in combination.

Spessartite.

To give all the localities for spessartite in this field would mean an enumeration of all pegmatite occurrences; therefore, it is not attempted. The best development of spessartite is at the mines near Ramona, and some very fine gem material has been obtained from there. Spessartite occurs most abundantly in the banded lower rock of the second-group pegmatites, and as a rock-forming mineral thereof it has already been described in Part I on page 000. Scattered through the graphic granite and the granular quartz-feldspar aggregate are isolated crystals or nests of crystals of spessartite. The garnet has also been found intergrown in graphic form with quartz. In the pay shoot of the pegmatites at Ramona, spessartite is found as isolated crystals (dodecahedron and trisoctahedron) in the loose material of the pockets, and also as large well-developed crystals of a beautiful light yellow brown color attached to tourmaline, feldspar (mostly albite), and muscovite in such a way that the spessartite must have been the last mineral formed. Plate XXVIII D shows a black tourmaline crystal to the outside of which are attached numerous small spessartites

Chemical composition.

The garnet from the lower banded rock of the unsymmetrical type of pegmatites was analyzed with the result shown below.

Analyses of spessartite, from lower banded rock. Katerina mine, Hiriart Hill, Pala.

Constituent	Sample
SiO_2--	37.06
Al_2O_3-	21.96
MnO--	20.41
FeO--	20.05
CaO--	0.08
MgO---	trace
Total-	99.56

Spodumene

Occurrence.

Spodumene has been found at Pala and at Rincon. Other reported occurrences, notably in Riverside County, could not be verified by the writer. At Pala, the mineral has been obtained in greatest quantity from the Pala Chief mine, but it has also been found in abundance at several of the mines on Hiriart Hill, notably the Katerina and the Naylor-Vanderberg. Spodumene has also been reported from the northern end of the large pegmatite on which the Stewart mine is situated.

Spodumene is one of the few minerals of the California pegmatites that rarely, if ever encloses any other mineral. Large altered crystals of spodumene firmly imbedded in the solid pegmatite rock (Plate XVIII B) are abundant in the Katerina mine. The unaltered spodumene, as found in pockets, is free from any attached mineral. Matrix specimens are also extremely rare, although several have been seen in which the spodumene is partly embedded either in quartz crystals or in scaly

cookeite. It has been stated that spodumene and tourmaline do not occur in the same pocket, although they both may be plentiful in two adjacent pockets.

The rareness with which other minerals occur with spodumene leads to the belief that it must have been one of the first minerals to form. The practical absence of any mineral inclusions is the more remarkable on account of the large size of the spodumene crystals. In extreme length these are excelled, as far as known, only by orthoclase,. quartz, and black tourmaline crystals. Plate XXIX shows reduced, photographs of some of the largest spodumene crystals.

Only crystals have been found; the mineral is not known to occur massive, although some of the crystals have been so attacked and dissolved by etching that in their present form no indication of their original crystal faces is seen. Spodumene is not known to occur molded over the form of other pre-existing mineral.

Crystallography.

The crystals of spodumene are so rounded by etching that very few of them except those in the prism zone show any well-defined crystal faces. A search of many crystals has yielded less than a dozen on which the terminal faces could be determined with a fair degree of certainty. The size of the largest crystals of spodumene from the Pala Chief mine, Pala, as far as can be ascertained, is shown below. They all belong to the variety kunzite. They are shown, one-third natural size, in Plate XXIX.

Dimensions of largest spodumene crystals (variety kunzite) from Pala.

Dimensions in centimeters	weight in grams	Location of specimen
30 by 11.5 by 2	340	Harvard University (Holden collection)
29 by 16 by 2	1,692	Tiffany & Co.
20 by 10 by 2	1,276	Harvard University (Holden collection)
18 by 8 by 3	1,000	(Not listed by Schaller)
17 by 11 by 1	528.7	(Not listed by Schaller)
22 by 8 by1.5	528.7	(not listed by Schaller)

Much larger altered crystals were seen embedded in the pegmatite at the Katerina mine, Hiriart Hill, Pala, a length of 3 feet being not very rare. The dimensions given in the table, however, are those of unaltered clear crystals taken from the mine.

PLATE XXIX. Spodumene crystals, Pala, One-third natural size.

Forms and angles.

The forms observed are as follows: b {010}, l{320}, a {100}, s {121}, m {110}, p {112}, n {130}, and A {350}

Both the measurement and the calculation of the angles of these forms are

given in the following table.

Measured and calculated angles, spodumene.

Form	Measured		'	
	φ	ρ	φ	ρ
b = 0∞ = 010	0°06'	90°00'	0°00	90°00'
a = ∞0 = 100	90°00'	90°00'	90°00'	90°00'
m = ∞ = 110	43°30'	90°00'	43°30'	90°00'
n = ∞3 = 130	17°06'	90°00'	17°33'	90°00'
A = ∞5/3 = 350	29°50'	90°00'	29°39'	90°00'
l = 3/2∞ = 320	55°01'	90°00'	54°54'	90°00'
s = 12 =121	37°14'	73°33'	38°46'	72°56'
p =1/2 = 112	21°05'	31°57'	20°55'	34°04'

The unit prism is always present, and measurements of 10 faces gave the following values:

Prism angle, m ∧ m' = (110) ∧ (1̄10)	
43°30'	43°31'
43°29'	43°28'
43°36'	43°26'
43°24'	43°33'
43°33'	43°30'
Average= 43°30'	

This value agrees with the one given by Dana[127] in his System of Mineralogy, but varies somewhat from the angle obtained by Brush and Dana[128] on cleavage faces of the Branchville, Conn., spodumene, their results giving 43° 36.5'.

Kunz [129] quotes Penfield as follows in regard to the value of the prism angle: " The prism faces were well developed and gave good reflections. The prismatic angle m ∧ m' = (110) ∧ (1̄10), on two crystals was found to be 86°45' ***[therefore, 9 = 43°22 1/2'} For comparison, measurements were made of the cleavage angle of spodumene from Branchville, m ∧ m' = 93° 14' [= 93° 23']."

The form A = ∞ 5/3 = {350} occurs but once, as a small face.

The form n = ∞ 3 = {130} was measured by means of a wax impression, as the crystal on which it occurs is too large for measurement with the reflection goniometer.

On the smaller crystals first found, the unit prism, although always present, is not always equally developed in its four faces, two parallel faces being frequently

[127] Dana, E .S., System of Mineralogy, 6th ed., p. 366: 1892

[128] Brush, G. F., and Dana, E. S., Third Branchville Paper:, Am. Jour. Sci., 3rd ser., vol. 20, p.257, 1880.

[129] Kunz, G.F., A new lilac-colored spodumene from Pala, Cal.: Am. Jour. Sci., 4th ser., vol. 16, p. 266, 1903.

much larger than the other two. Thus, the crystal presents a tabular appearance.

The orthopinacoid is frequently present--rarely,. as a very narrow face rounded to such an extent as to render difficult the determination if it be present or. not; much more commonly, the orthopinacoid is very broad, making the crystal tabular. A marked feature of the orthopinacoid is that it is always deeply furrowed vertically.

The clinopinacoid is of frequent occurrence, as a narrow face varying in width from less than a millimeter to more than a centimeter.

The pyramid faces are all dull and etched and yield no sharp signal. Figures 96 and 97 show two terminated spodumene crystals.

Figure 96 Tabular spodumene crystal. Forms: a {100}, m {110}, b {010}, o {111}.

Figure 97 Stouter spodumene crystal. Forms: a {100}, m {110}, b {010}, p {011}.

Habit.

Two distinct habits were noted on these crystals. The first habit is prismatic and is due to the equal development of the prism m {110} and the two pinacoids b {010} and a {100}, the crystal being octagonal in shape and elongated parallel to the c axis. The second habit is tabular and, rarely, is due to the inequality in size of the prism faces. Other faces, such as the pinacoids, are usual1y absent from crystals of this type. The most ?-equant type of the tabular habit is where the orthopinacoid is very large and the crystals become tabular parallel to this form. This habit occurs commonly on the larger crystals.

Twinning

Though the writer stated in 1903[130] *"that the specimens that form the subject of this study are untwinned,"* it is the fact that many of the crystals found since that time are twinned on the orthopinacoid. This twinning can be readily detected by means of the etch figures that show two orientations on the same face, as is shown diagrammatically in the figure 98.

Etch Figures.

A very marked feature of the spodumene crystals is the profusion of natural etch figures (Plate XXX), which thickly crowd all of the natural faces of the crystals. Even cleavage (prismatic) pieces frequently show them.

On the faces of the unit prism, they are especially thick. The etch figures are usually triangular in shape and vary in size from a maximum of several millimeters in length to those of microscopic size. Frequently, there will be several smaller figures in the base of a larger one. Occasionally, a long string of the figures extend across a prism face in an approximately horizontal direction.

The orientation of these triangular pits with reference to the crystallographic directions varies somewhat, but, in general, is fairly constant and is shown in figure 98. The position of these figures on the four prism faces is shown in figure 99. It is noticed that they always point away from the orthopinacoid, and the angle (nearly 90°) is nearest the clinopinacoid. Rarely, the triangle passes into a trapezium by the

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[130] Schaller, W.T., Spodumene from San Diego County, California: California Univ. Dept. Geology Bull., vol. 3, p. 275, 1903.

addition of a fourth side, as is shown in the middle figure of figure 98; very few of the edges are perfectly straight, being more or less rounded (but they are mostly all drawn straight.)

Figure 98 Position of etch figures on unit prism, spodumene.

Figure 99 Position of etch figures on four unit prisms of spodumene.

PLATE XXX Etchings on spodumene crystals. A.   Triangular etchings on the prism m {110}, B. Distorted triangular etchings on the prism m {110}, C. Etchings on twinned composite face of m {110}, D. Etchings on clinopinacoid b {010}, and E. Etched crystals.

The faces forming the etch figures were originally referred to certain crystallographical planes to which the symbols {110}, {320}, {8.14.3} or {351}, and {11.10.3} were assigned. Measurements of faces of etch figures.

[Orientation of spodumene as given in Goldschmidt's Winkeltabellen]

Form	Measured		Calculated	
	ϕ	ρ	ϕ	ρ
$m = \{110\}$	43°24'	90°00'	43°30'	90°00'
	55°49'	90°00'	54°54'	90°00'
	55°40'			
	56°09'			
	Av. 55°53'			
$y = \{8.14.3\}$	34°33'	81°44'	34°20'	82°04'
or	34°44'	82°19'		
simply	32°33'	82°04'		
↓	Av. 33°57'	Av. 82°02'		
$y = \{351\}$	33°57'	82°02'	35°01'	82°39'
$z = \{11.10.3\}$	40°44'	80°20'	40°15'	79°47'
	40°29'	79°25'		
	41°06'	80°06'		
	40°23'	79°22'		
	Av. 40°41'	Av. 79°48'		

These faces, however, grade into each other and the surfaces are all rounded, so that the positions indicated by the indices given represent in fact only approximate positions for which the surface yields a brightest reflection. Further study of these etch figures has shown that they are not plane crystal faces and that assignment of definite indices to their rounded surfaces is incorrect.

The etch figures occurring on the clinopinacoid are rhombic in shape and sometimes modified by another plane, as is shown in figure 100. A few of the etch figures run over on the clinoprism {130}, the clinopinacoid here shown being the negative one. Strings of the etch figures also occur pitching in a direction opposite to

that of the clinoaxis. There are two prominent varieties, the rhombic, nearly equal in the two directions, and a distorted long narrow form.

On some crystals the etch figures represent the exterior of cavities that penetrate the entire crystal, emerging on the opposite clinopinacoid. These cavities are usually partly choked up by a limonitic, earthy substance, probably the impure brown clay so abundant in the pockets of the pegmatites.

Figure 100 Position of etch figures on clinopinacoid, spodumene.

Etch figures also cover the rounded ends of the crystals, but their relation to the structure of the crystals was not determined. In fact, the entire question of the etching and solution processes, which have yielded such remarkable forms as are found on these spodumenes, was not further studied as the problem has been already worked out by Dr. Berberich, one of Professor Goldschmidt's students.

The various etchings observed on spodumene are partly shown in Plate XXX.

Physical properties.

The prismatic cleavage, parallel to m {110}, is perfect and many of the crystals as obtained from the mine are bounded by cleavage faces thickly covered with etch figures. No parting parallel to the orthopinacoid was noticed on any of the crystals.

The density was determined as 3.189. Kunz gives the values 3.179, 3.185, and 3.187 for similar material.

The behavior of the kunzite variety of spodumene with ultraviolet light, Roentgen rays, and various forms of radioactivity has been studied by Kunz and Baskerville[131]127 from whose description the following paragraphs are taken.

"In a recent investigation made by us on the behavior of a large number of minerals and gems with various forms of radiant energy, including the emanations, as well as on the production of luminescence in some cases by other physical means, the new variety of spodumene, designated kunzite, was found to be peculiarly sensitive and to exhibit some remarkable properties."

In general, as shown by these investigations, the gem-minerals were little affected by ultra-violet rays; but three species exhibited a high degree of responsiveness to these and to all forms of radioactivity, so far experimented with. These minerals were diamonds of certain kinds; willemite (zinc orthosilicate), which in some cases has been used as a gemstone, and kunzite. The behavior of the last, as noted in various experiments, is unique and will be briefly described here by itself.

1. Attrition and heat. Kunzite does not become luminous by attrition or rubbing. Several specimens were held on a revolving buff cloth making 3,000 revolutions per minute, so hot as to be almost unbearable to the hand, and still it failed to become luminous. Wollastonite, willemite and pectolite are, however, very triboluminescent. As to luminescence induced by heat alone, it was found the kunzite does possess the property of thermo-luminescence to some extent, with an orange tint and at a low degree of heat.

2. Electricity.-The mineral assumes a static charge of electricity, like topaz, when rubbed with a woolen cloth. On exposing kunzite crystals of different sizes to the passage of an oscillating current obtained from large Helmholtz machines, the

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[131] Baskerville, C., and Kunz, G.F., Kunzite and its unique properties: Am. Jour. Sci., 4th ser., vol. 18, pp. 25-28, 1904.

entire crystal glowed an orange-pink, temporarily losing its lilac color. A well-defined, brilliant line of light appeared through the center, apparently in the path of the current. On discontinuing the current, the crystal gave the appearance of a glowing coal. It was not hot, however, and the phosphoresence lasted for forty-five minutes.

Three large crystals, weighing 200, 300, and 400 grams each, were attached to copper wires so that the current passed from below upward, in one case lengthwise of the prism and in the other across the width of it. In each Instance the crystals became distinctly luminous, a pale orange-pink, and between the two wires a bright almost transparent line passed from one wire to the other; in reality, as if two elongated cones crossed each other, the line of the path being transparent at the sides, whereas the rest of the crystals appeared translucent. After the exposure of two minutes they were laid upon photographic plates, and in five minutes produced a fine auto-print. The crystals continued to glow for forty-five minutes.

When a cut gem is suspended between the two poles it becomes an intense orange-pink color, glowing with wonderful brilliancy. The discharge seemed as if it would tear the gem asunder, although actually it was unaffected.

3.   ultraviolet rays.-These Invisible rays, produced by sparking a high voltage current between iron terminals, caused kunzite, white, pink, or lilac, to prosphoresce for some minutes. The white responded most readily.

4.   Roentgen or X-rays.-All forms of kunzite become strongly phosphorescent under these rays. An exposure of half a minute caused three cut gems to glow first a golden pink and then white for ten minutes. The glow was visible through two thicknesses of white paper which was held over it. A large crystal excited for five minutes afterwards affected a sensitive photographic plate.[132] Another crystal exposed for ten minutes was laid for five minutes on a sensitive plate.[133] The resulting autophotograph was clear and distinct, but presented a very curious aspect not seem by the eye-as of a misty or feathery outflow from the side and termination of the crystal, suggesting an actual picture of the invisible lines of force. The other varieties of spodumene, natural mineral and cut gems, failed to show this property. We are not yet in a position to offer a satisfactory explanation of this fact.

5.   Conduct with radium preparations.-Exposed for a few minutes to radium bromide with a radio-active strength of 300,000 (uranium being taken as unity), the mineral becomes wonderfully phosphorescent, the glow continuing persistently after the removal of the source of excitation. The bromide was confined in glass. Six hundred grams of kunzite crystals were thus excited with 127 milligrams of the radium bromide in five minutes. The effect is not produced instantaneously, but is cumulative, and after a few moments' exposure the mineral begins to glow, and its phosphorescence is pronounced after the removal of the radio-active body. The luminosity continued in the dark for some little time after the radium was taken away. No other varieties of spodurnene examined, including hiddenite, gave like results. In this respect, as with the Roentgen rays, the kunzite variety stands by itself.

When pulverized kunzite is mixed with radium-barium chloride of 240 activity or with carbonate of lower activity the mixed powder becomes luminous and apparently remains so permanently; i.e, in several months no loss has been observed. The same is the case if pulverized wollastonite or pectolite be used instead of the kunzite. When either of these mixtures is put in a Bologna flask and laid on a heated metal plate (less than red hot) the powder becomes incandescent and remains so for a long time after removal. These three minerals phosphoresce by heat alone, as was mentioned

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[132] Science, new ser., vol. 18, p. 303, 1903.
[133] This test was made by Dr. H.G. Piffard, of New York City.

above In regard to kunzite. Perhaps this luminosity of the mixed panders at the ordinary temperature may be accounted for in part by the evolution of heat[134] 130 on the part of the radium compounds, but there are experimental reasons which cause us to reject such explanation for the total effect.

The emendation of radium, the a-rays, according to Rutherford are condensed at a temperature of -13Cr to -140" C. The emanations were driven from radium chloride by heat and condensed with liquid air on a number of kunzite crystals, according to a method which will be described by one of us {B) and Lockhart in another paper, and no phosphorescence observed. Consequently kunzite responds only to the r-rays, which are believed to be virtually roentgen rays.

6.   Actinium.-A sample of the still more rare and novel substance discovered by Professor Debieme and received from him through the courtesy of Professor Curie, was also tried as to its action upon kunzite and some other minerals. The actinium oxide, with an activity of 10,000 according to the uranium standard, gave off profuse emanations and affected diamonds, kunzite and willemite in a manner similar to the radium salts, with quite as much after-continuance.

However, we have not tried the condensation of these emanations upon the minerals by refrigeration. The peculiar properties of the kunzite variety of spodumene, which have been enumerated, have not been observed in any other of the gem or gem-minerals that we have examined. It is barely possible that the same amount of manganese may have much to do with it, but from our present knowledge basing a chemical explanation thereon is idle."

Optical properties.

Color.

The colors of the transparent kunzite have been described as delicate to deep rose-lilac, amethystine, lilac-pink, rose-pink, lilac, lavender, magenta, amethystine purple, yellow-white, pale green. colorless. Inasmuch as these crystals are highly pleochroic, it is difficult to define the color of a certain specimen accurately as the color will vary according to the position in which the crystal is held. For reproduction of the characteristic color of these kunzite crystals, see Plate XXXI, which is described further under the heading of pleochroism. The colors of the beautiful gem stones that can be cut from kunzite are also shown in Plate XXXI. There are two general colors shown by the deeply colored crystals, which may be distinguished as reddish purple (Plate XXVI A) and bluish purple (Plate XXXI B, C). A similar distinction in color was noted for lepidolite (p. 000).

Large numbers of the crystals are perfectly transparent and show no trace of alteration, being remarkably fresh. Others are opaque and completely altered either to cookeite or to a form of clay. The effect of exposure to the air is to decolorize the crystals, as those found on or near the surface were very light colored or nearly colorless; however, those obtained at some depth are much deeper colored.

PLATE XXXI. Spodumene, variety kunzite. A. Red-lilac variety B. Blue-lilac variety C. Blue-lilac endwise. D. Gem-stone from red-lilac variety. E. Gem-stone from blue-lilac variety.

The color, although rare, is not new, as it has been noted on some of the

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[134] P. Curie and Laborde, Comptes Rendus, vol. 136, p. 673

spodumene from Branchville, Connecticut, described by Brush and Dana, as "of a fine amethystine color. ••• In the better specimens the spodumene is perfectly transparent, sometimes colorless, and again of a beautiful rose-pink or amethystine-purple color." The spodumene found in Madagascar has also a rose-pink color. But the deep colored kunzite crystals from Pala are unequaled in the wonderful depth and beauty of their coloration and far excel all other known occurrences of the mineral.

Orientation.

The optical orientation of kunzite is shown in figure 101. The axial plane is parallel to {010} and the obtuse bisectrix Z is nearly parallel with the a axis. The average of a number of determinations of the inclinations of the acute bisectrix to the vertical axis, gave, for sodium light, BXa Λ = 25 l/2°. That is, the acute bisectrix, X, lies in the obtuse angle J3 and is nearly normal to the basal pinacoid (Dana's orientation).

Figure 101 0ptical orientation of spodumene.

Refractive Indices.

The indices of refraction were determined on a pink crystal and on a colorless one with the following results.

Refractive indices for kunzite.

Pink crystal	Colorless crystal
$\alpha = 1.652$	$\alpha = 1.65$
$\gamma = 1.679$	$\gamma = 1.68$

Pleochroism.

The pleochroism is a very striking property of the mineral. The writer earlier described it as X= magenta or amethystine-purple, Y = pale pink or amethyst, Z = colorless. The Z ray is absolutely colorless, no matter how thick the crystal is. Baskenille[135] has described it as follows:
"… the spodumene dichroism from a very pale tinge when observed transversely to the prism to a rich amethystine hue longitudinally." Kunz136132 states: 'with the dichroscope the darker specimens show a rich deep purple for the ordinary ray and a pink for the extraordinary ray. In the lighter crystals, almost like pink topaz in color, the ordinary ray is pink and the extraordinary ray almost white.' "

The deeper colored crystals show either a reddish-purple color (Plate XXXI A) or a bluish-purple color (Plate XXXI B, C). The pleochroism of the reddish-purple

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[135] Baskerville, C., Kunzite: a new gem: Science, new ser., vol. 18, p. 304, 1903.
[136] Kunz, G. F., The production of precious stones in 1903. U.S. Geol. Survey Mineral Resources p. 37, 1904.

crystals is as follows: X= phlox-purple[137], 133 the depth depending on the length of the crystal; Y =pale phlox-purple: Z =colorless. The view of the crystal shown in Plate XXXI A is obliquely against the orthopinacoid so that the resultant color shown is intermediate between Z and X. The deeper color parallel to X can be seen on the lower edges of the crystal. The pleochroism of the bluish-purple crystals (Plate XXXI B, C) is as follows: X= deep lilac, Y = purple, Z = colorless. The deep lilac of X is shown in Plate XXXI C, the purple of Y on the lower edge of Plate XXXI B, which nearly represents the colorless Z in the main part of the crystal. The direction of Z is generally of a smoky-gray color with a tinge of purple, the striations on the orthopinacoid causing some purple light of Y to come through the crystal.

Chemical properties.

The mineral has been analyzed by R. O. E. Davis[138] and W.T. Schaller[139] with the result shown below:

Analysis of kunzite, Pala.

Constituent	Schaller, analyst	Davis, analyst
SiO_2--------	64.42	64.05
Al_2O_3-----	27.32	27.30
Fe_2O_3-------	0.00	---
Mn_2O_3----	0.15	---
MnO--------	---	0.11
NiO---------	---	0.06
ZnO--------	---	0.44
CaO--------	0.00	0.80
MgO--------	0.00	0.00
Li_2O-------	7.20	6.88
Na_2O-------	0.39	0.30
K_2O--------	0.03	0.06
On ignition	0.00	0.15
Total---	99.51	100.15

The lime, zinc, and nickel, in the analysis by Davis, are unusual and peculiar ingredients. Otherwise, the two analyses agree well with each other and \\'ith the theoretical percentages.

Alteration

Kunzite has been found altered at all of its occurrences at Pala, though a much

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[137] Phlox purple is a reddish blue to red in hue, of high saturation and brilliance.
[138] Davis, R. O. E., Analysis of kunzite: Am. Jour. Sci., 4th ser., vol. 18, 1904.
[139] Schaller, W.T., Spodumene from San Diego Co., California: California Univ.Dept. Geology Bull., vol. 3, p. 274, 1903.

larger amount of the mineral is altered at the Katerina mine than at the Pala Chief mine. The alteration yields cookeite or pink clay, which retains the form and cleavage of the original spodumene.

Tourmaline Group.

The name tourmaline, often applied as a definite mineral species, is in reality a group name comprising several well-defined species differing from one another in composition and physical properties. The term tourmaline is on a par systematically with the terms mica, garnet, and feldspar. The individual species, whose mixtures form the various tourmalines, have already been recognized by those who have made a special study of the tourmaline group and are commonly called as follows:

(1) alkali or lithium tourmaline,
(2) iron tourmaline,
(3) magnesium tourmaline.

It is the purpose of this section on the tourmaline group to inquire further into this question and to attempt to definitely define the individual species with regard to composition and other properties. For that purpose the tourmalines from California were utilized as far as possible, and, in addition, the literature was drawn on wherever available.

The problem of the chemical composition of tourmaline can only be solved by a careful correlation of the various properties with the chemical composition. A review of the literature shows that with one notable exception, the problem has been attacked only from the chemical side, the physical and crystallographical properties not being considered. When Riggs published[140] his suite of tourmaline analyses in 1888, different authors published numerous interpretations of these analyses. A solution of the problem of the chemical composition was attempted, not by a consideration of the properties of the mineral tourmaline but by a mathematical calculation of the analytical figures obtained by Riggs. Needless to say such interpretations gave rise to much controversy, as it was possible to deduce almost any formula from the analyses and to find particular results that agreed \\ith the theoretical calculations.

The chemical composition was further studied by Penfield and Foote[141] who in 1899 published the general formula $H_9Al_3(B,OH)_2Si_4O_{19}$ for tourmaline and showed that all varieties of the mineral could be referred to this type formula. In the next year, Wülfing[142] published a long paper dealing with the crystallographical and physical properties of the mineral and traced certain relationships between the variations in these properties and the chemical composition. Wülfing definitely established the fact that the properties of the different tourmalines were not constant but varied somewhat. With the results obtained by Penfield and Foote on the chemical side and by Wülfing on the physical side, it is possible to go ahead and extend the research into the tourmaline problem by correlating these two sides of the question.

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[140] Riggs, B. R., The chemical composition of tourmaline: Am. Jour. Sci., 3rd ser., vol. 35, p. 35, 1888.

[141] Penfield, S.L., and Foote, H.W., The composition of tourmaline: Am. Jour. Sci., 4th ser., vol. 7, p. 97, 1899.

[142] Wülfing, E.A, Some crystallographical constants of tourmaline and their relations to its chemical composition: Programm zur 82 Jahresfeier K. Württ. Landw. Akad. Hohenheim, 1900.

The ideal way of studying a mineral series by a correlation of the chemical and physical properties, is to prepare the series synthetically; as in this way, the individual components and all desired mixtures can be obtained whose chemical composition is known synthetically and can be readily checked analytically. Such a method is not possible for tourmaline, and we must depend on natural crystals. Various factors, such as scarcity of well-crystallized material, the presence of impurities (known and unknown), and the lack of abundant material suitable for a complete study of all the properties--all these tend to make the tourmaline problem a very difficult one. For a strict correlation, all of the determinations should be made on the same sample; then a direct comparison of the properties is valid. For tourmaline, however, this can not be done and it becomes necessary to group together the properties of material, apparently, but not necessarily, identical.

The specific problems considered in this section are three and are as follows: (1) to test the formula proposed by Penfield and Foote by new analyses; (2) to see if definite formulas can be proposed for the mineral; (3) to see if a correlation between the chemical composition and the other properties of tourmaline can be determined.

It should perhaps be stated that the samples used for analyses were carefully selected and their purity assured. The rninimum and maximum density of the actual fragments analyzed was determined by the Thoulet solution (except for the black tourmaline from Ramona whose density was determined by direct weightings.

In all the analyses given here the state of oxidation of the titanium, iron, and manganese is arbitrarily given and in the calculation of the ratios is changed to this arbitrary form.

The titanium is regarded as Ti_2O_3 and as replacing Al_2O_3, for reasons already explained by Penfield and Foote.[143] 139 The iron is all stated as Fe_2O_3; the small amounts of sesquioxide reported may result secondarily, as for example by the fine grinding of the sample. The manganese is stated as MnO, but it is very probable that in the pink tourmaline where its amount is very small, it is largely present as Mn_2O_3, replacing the alumina.

Description of individual tourmalines.

1. Pale pink crystals from Elba.

A lot of small pale-pink tourmaline crystals were purchased from the Foote Mineral Co., which wrote in regard to them: "All of these were secured in exchange from the late Professor Bombicci, who collected them in Elba many years ago." In places on some of the crystals the pale-pink color nearly disappears or is replaced by a very pale green or blue. A study of the pale-pink tourmaline from Elba was made in connection with the work on those from California, as the older analysis by Rammelsberg seemed to indicate that these Elba tourmalines contained a minimum amount of FeO, MnO, CaO, and Mg and were, therefore, perhaps close to one of the simpler components of the tourmaline series.

The crystal faces were not very well suited for accurate measurements as most of them were dull and uneven. Two crystals yielded fairly good reflections and on them the following angles were measured.

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[143] Penfield, S.L, and Foote, H. W., The composition of tourmaline: Am Jour. Sci., 4th series., vol. 7, p. 97, 1899.

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No.1   c ∧ r = 27° 10'   c axis   = 0.4444
        c ∧ r' = 27° 12'   = 0.4451

No.2   c ∧ r = 27° 11'   Average   = 0.4448

The measurements of D'Achiardi on similar crystals from Elba show, as stated by Wulfing, so great a variation that the values obtained by him cannot be considered accurate enough to be used.

The density of the material analyzed was between 3.043 and 3.050, average= 3.05. This value is slightly higher than that (3.022) given by Ramrnelsberg for similar tourmalines from Elba.

The refractive indices, for sodium light, were determined on two crystals selected from the lot analyzed. The results obtained are

	ω	ε	$\omega - \varepsilon$
Crystal No. 1	1.652	1.630	0.022
Crystal No. 2	1.650	1.630	0.020
Average	1.651	1.630	0.021

These values are slightly different from those obtained by other authors on similar material from Elba. Thus:

Author	Crystal color	ω	ε	$\omega - \varepsilon$
Viola a	yellow	1.6494	1.6239	0.0255
Viola	colorless	1.6425	1.6215	0.0210
Viola	green	1.6503	1.6254	0.0249
Zimanyi b	colorless	1.6386	1.6202	0.0184
D'Achiardj c	colorless	1.641-1.644	1.622-1.623	0.019-0.021
D'Achiardi d	(not given)	1.642	1.622	.020

a Zeitscht. Kryst. Min., vol. 32, p. 557.
b Zeitscht. Kryst. Min., vol. 22, p. 333.
c Zeitscht. Kryst. Min., vol. 26, p. 213. Proc. verb. Soc. Tosc. Sci. Nat. 4 March, 1894.
d Zeitscht. Kryst. Min., vol. 30, p. 201. Le Tourmaline del granite Elbano. pt II, 1896.

As will be specially noted later, the particular Elba tourmalines studied by the ·writer show deviations in their properties from those determined on other Elba tourmalines of apparently similar nature.

The chemical analysis of the Elba tourmaline is given below followed first by a ratio calculation on the basis of the "hydrogen equivalent" as deduced by Penfield and Foote for the bases and then by the ordinary molecular ratios.

Analysis of tourmaline from Elba

Constituent	Analyses	Hydrogen equivalent			Molecular ratios	
SiO_2	37.89	---	0.632	—4.00	0.632	—12.00
B_2O_3	10.28	---	.147	—0.93	.147	—2.79
Al_2O_3	43.85	2.580			.429	—8.16
Ti_2O_3	.04	.002			---	
FeO	.11	.003			.001	
MnO	.11	.003			.002	
CaO	.07	.003			.001	
MgO	.00	---			---	1.86
K_2O	.00	---	3.172	—	---	
Na_2O	2.43	.079		20.08	.039	
Li_2O	1.66	.111			.055	
H_2O	3.47	.386			.193	—3.72
F	.10	.005			.005	
Subtotal	100.01					
Less O	.04					
Total	99.97					

The analysis shows an unusually high percentage of alumina, but the one by Rarnmelsberg on similar material likewise shows a very high (44.05 percent) alumina content. In the discussions given in this report, this particular tourmaline ·will, for the sake of brevity, be referred to as No. 1, the other tourmalines are similarly numbered from 2 to 16, respectively.

2. Pink crystals from Mesa Grande.

The transparent pink crystals from the Himalaya mine, Mesa Grande, San Diego County, were collected by the writer and represent ideal material for investigation. Two crystals possessing brilliant terminations were measured and the average values for the c axis deduced there from are as follows:

crystal No. 1 6 faces of {2131}   c= 0.4475
crystal No.2   6 faces of {2131}   c= 0.4483
     Average ---0.4479

The density of the material analyzed lay between 3.033 and 3.039 with an average value of3.036. This similar value is verified by the additional determinations on similar material as follows:

One pink crystal   3.038
Pink crystals from Oak Grove, California-- 3.033
Pink crystals from Pala, California---------- 3.024

The refractive indices were determined (sodium light) on five different crystals with the following results:

Crystal	ω	ε	ω - ε
No. 1	1.648	1.628	0.020
No. 2	1.646	1.628	.018
No. 3	1.645	1.628	.017
No. 4	1.647	1.629	.018
No. 5	1.648	1.628	.020
Average	1.647	1.628	.019

The analysis, with the corresponding ratios, are shown in the tabulation below.

Analysis of pink tourmaline from Mesa Grande.
- - - - - indicate not applicable. W.T. Schaller, analyst]

Constituent	Analysis	Hydrogen equivalent			Molecular ratios	
SiO_2-------	37.57	---		0.623—4.00	0.623—12.00	
B_2O_3-------	10.65	---		.152—0.97	.152—2.91	
Al_2O_3-----	42.18	2.478			.413—7.95	
Ti_2O_3------	trace	---			---	
FeO---------	.19	.006			.003	
MnO-------	.24	.006			.003	
CaO--------	1.20	.042		3.122—20.05	.021	2.40
MgO-------	.00	---				
K_2O--------	.00	---				
Na_2O-------	2.05	.066			.033	
Li_2O-------	1.92	.128			.064	
H_2O-------	3.38	.376			.188	3.81
F-----------	.39	.020			.020	
Total---	99.77					

3. Pale-green crystals from Mesa Grande.

The pale-green crystals analyzed were found with the pink ones just described. Material suitable for accurate crystal measurement was very scarce and the only determinations of value are the following two, made on one crystal.

$$c \wedge r = 27° \, 22' \qquad c - axis \qquad = 0.4483$$
$$c \wedge r' = 27° \, 26' \qquad c - axis \qquad = 0.4495$$
$$Average = \qquad 0.4489$$

This value is confirmed by the measurements of pale-green crystals from the Stewart mine, at Pala, of which there was not enough material for chemical analysis. The other properties of the crystals from the two localities agree fairly well, so that the closeness of the values for the c axis confirms the correctness of the above value given for the crystals from Mesa Grande.

The Pala crystals are small and very brilliant. The chief forms, outside of those in the prism zone are {077bar2}, {21$\bar{3}$1}, {10$\bar{1}$r1} and {022bar1}. The rhombohedra

yielded excellent reflections and from the complement of the angle between the rhombohedron face and the prism zone, the following values were
obtained for the c-axis, from the ten crystals measured:

Determination of value of c axis, pale green crystals, Stewart mine, Pala.

Crystal No.	Number of measurements	Limits	c- axis
1	9	0.4473 - 0.4500	0.4485
2	9	0.4482 - 0.4499	0.4492
3	s	0.4492 - 0.4S13	0.4501
4	9	0.4485-0.4512	0.4495
5	6	0.4479 - 0.4502	0.4488
6	9	0.4486-0.4521	0.4495
7	7	0.4473 - 0.4507	0.4489
8	3	0.4505 - 0.4507	0.4506
9	6	0.4487 - 0.4505	0.4495
10	8	0.4482 – 0.4502	0.4492
Average	71		0.4493

The average value of the c axis obtained on the Pala crystals (0.4493) is so close to that found on the crystals from Mesa Grande (0.4489) that the later value is confirmed and may be considered accurate. There is also a close agreement in the values of the densities and refractive indices for the crystals from Mesa Grande and Pala, as is shown below.

The density of the crystals analyzed (from Mesa Grande) lay between 3.040 and 3.046, with an average value of 3.04. The density of the Pala crystals is 3.053.

The refractive indices were determined on one crystal from Mesa Grande and on four crystals from Pala.

Locality	ω	ε	$\omega - \varepsilon$
Mesa Grande	1.646	1.628	0.018
Pala, No. 1	1.646	1.628	0.018
Pala, No. 2	1.647	1.625(?)	0.022
Pala, No. 3	1.646	1.627	0.019
Pala No. 4	1.647	1.628	0.019

The analysis made on selected fragments of the pale-green crystals from Mesa Grande, is as follows:

Analyses of pale green tourmaline from Mesa Grande.
 ---- means not calculated or data not given. W.T. Schaller, analyst

Constituent	Analyses	Hydrogen equivalent	Molecular ratios
SiO_2	36.72	- 0.609--4.00	0.609 12.00
B_2O_3	10.60	- 0.151-0.99	0.151 2.97
Al_2O_3	41.27	2.423	0.404 7.98
Ti_2O_3	0.06	0.003	0.001
FeO	1.13	0.032	0.016
MnO	1.48	0.042	0.021
CaO	0.87	0.028	0.014 2.85
MgO	0.00	---- 3.102-20.37	---
K_2O	0.00	----	---
Na_2O	2.23	0.072	0.036
Li_2O	1.76	0.116	0.058
H_2O	3.33	0.370	0.185 3.81
F	0.31	0.016	.016
Subtotal	99.76		
Less O Total	0.13		
	99.63		

4. Green crystals from Haddam Neck, Connecticut.

The crystals here described are those analyzed by Penfield and Foote.[144] 140 Professor Penfield was so kind as to send me, shortly before his death, the lot of crystals from which the material for his analysis was selected. I searched the material for crystals on which accurate measurements could be made but was unable to find any suitable ones.

The density of the analyzed material is given as 3.089, which may be stated as 3.09.

Two crystals, one light green and the second one deep green, were selected and the refractive indices determined.'

Crystal	ω	ε	ω - ε
Light green	1.649	1.630	0.019
Dark green	1.652	1.631	0.021
Average	1.641	1.631	0.020

From the analysis of Penfield and Foote (here not repeated), the following ratios are deduced:

SiO_2	12.00
B_2O_6	3.06
Al_2O_3	7.56
RO	3.39
H_2O	3.93

5. Blue crystals from Pala.

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[144] Penfield, S.L, and Foote, H.W., The composition of tourmaline: Am. Jour. Sci., 4th ser., vol. 7, p. 97, 1899.

Some very small blue crystals were collected in the Pala Chief mine, at Pala. The small crystals generally give good reflections from the faces of the unit rhombohedrons and the angles between these faces, and the prism zone was accurately measured 24 times on 12 crystals. The average value obtained is c ∧ r = 27°27', c = 0.4499.

Limits 27°19' - 27°38', c = 0.4473 - 0.4534.

The density is from 3.110 to 3.114, average 3.11.

The refractive indices were determined on one crystal to be as follows:

$\omega = 1.650$ $\quad \varepsilon = 1.630,$ $\quad (\omega - \varepsilon) = 0.020$

Unfortunately, not enough material could be obtained for a chemical analysis, and the writer had, therefore, to refer to an analysis of apparently similar material made by Scharizer.[145] 141 The density of this blue-black tourmaline is given as 3.103 or very close to that of the crystals from Pala. Scharizer's analysis is reproduced here, with the ratios calculated there from.

Analysis of blue-black tourmaline from Schüttenhofen
--- means value not calculated or data not given. R. Scharizer, analyst.

Constituent	Analysis	Molecular ratios
SiO_2-------	36.38	0,606—12,00
B_2O_3------	(8.12)	.116—2.31
Al_2O_3-----	39.77	.390—7.71
FeO--------	4.17	.058
MnO------	2.83	.039 3.72
Na_2O------	1.93	.031
K_2O-------	.93	.009
Li_2O-------	1.54	.051
H_2O-------	4.29	.238—4.71
Sn_2O------	.04	---
Total---	83.76	

In this analysis the boron percentage is too low and the amount of water stated is probably high. The ratio of the "hydrogen equivalent" to silica as given by Penfield and Foote is 21.0 to 4 instead of 20.0 to 4 and the higher value is probably largely due to the water content, which as stated again on page 000 is probably too large.

6. Black crystals from Ramona.

In the Surprise mine, near Ramona, San Diego County, large black tourmaline crystals are found in pegmatite. The tourmalines present three phases-one in which the tourmaline crystal is almost entirely altered to a compact, scaly muscovite; a

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[145] Scharizer, R., The chemical constitution and color of tourmaline from Schüttenhofen: Zeitscht Kryst. Min. vol. 15, p. 337, 1889.

second in which the unaltered shining black tourmalines are covered with prismatic muscovite crystals, which in their genesis, have no relation to the mineral to which they adhere; and third, as brilliant black crystals, usually terminated, and free from any adhering mica or other mineral. Two crystals were found that apparently were suitable for accurate measurement, but when examined on the goniometer, it was found that each rhombohedron face, though highly polished, gave two distinct reflections, over a degree apart. Both crystals showed this peculiarity. One set of values gave a calculated c axis, corresponding to that obtained for the material from Elba; the second value yielded an abnormally high value, namely 0.4647. Until the double reflections are explained otherwise, the average of the two sets of values must be taken to represent the value of the c axis for the black tourmaline from this locality. The measurements are as follows:

Crystal	(1)	(2)	Average
No. 1 $c \wedge r$ = 27°03' -	28°15'	27° 39'	
No. 1. $c \wedge r$ = 26°52' -	28°05'	27° 29'	
No. 1 $c \wedge r$ = 26°59' -	28°13'	27° 36'	
No. 2 $c \wedge r$ = 27°10'-	28°17'	I 27° 44'	
No. 2 $c \wedge r$ = 27°17' -	28°14'	26° 46'	
No.2 $c \wedge r$ = 26°58'-	28°14'	27° 36'	
Overall average---		27° 38'	

From the average value of the angle $c \wedge r$, the c axis is calculated as 0.4534. The density of one of the two crystals is 3.221. The second crystal was broken into two parts, the terminated end (density 3.225) was kept and the remainder of the crystal (density 3.222) was analyzed. The average value of the density is, therefore, 3.22.

The refractive indices were not determined on the material from Ramona. but a probable value was deduced by taking the average of different determinations made by Wülfing on black tourmalines of similar high density.

Locality	Density	ω	ε	$\omega - \varepsilon$
Alabaschka	3.195-3.222	1.6624	1.6325	0.0299
Auburn	d3.209-3.214	1.6664	1.6368	0.0296
Haddam	3.220-3.221	1.6689	1.6378	0.0311
Andreasberg	3.240	1.6763	1.6428	0.0335
Average-	1.669		1.638	0.031

The average values deduced are those taken for the black tourmaline from Ramona. It is to be noted, however, that the chemical composition of these different tourmalines varies somewhat so that they do not accurately represent the same variety.

The chemical analysis and ratios deduced there from are shown in the tabulation below.

Analysis of black tourmaline from Ramona.
---- indicates that values were not calculated or data not given.
W.T. Schaller, analyst

Constituent	Analysis	Hydrogen equivalent		Molecular ratios	
SiO2	35.21	----	0.584-4.00	0.584- 12.00	
B2O3	10.43	-----	0.149-1.02	0.149- 3.06	
Al2O3	36.07	2.118		0.353- 7.29	
Ti2O	00.23	0.010		0.002	
FeO	11.11	0.308		0.154	
MnO	00.98	0.028		0.014	4.29
CaO	00.25	0.008		0.004	
MgO	00.19	.009	2.933-20.09	0.005	
K2O	---	---		---	
Na2O	01.92	0.062		0.031	
Li2O	trace	----		----	
H2O	03.51	0.390		0.195	4.02
F	00.00			----	
Total-	99.90				

7. Black crystals from Lost Valley, San Diego County.

The crystals here described were collected by Mr. Bert Simmons, of Aguanga, Riverside County, California, who found them at the locality given as isolated crystals lying loose in the disintegrated granitic soil. They consist of shining black needles and, though opaque, seem to be very homogeneous and pure. No terminated crystals were found on which accurate measurements could be made.

The density of the sample analyzed lay from 3.154 to 3.157, average value being 3.16.

Analysis of black tourmaline from Lost Valley.
 ---- indicates that values not calculated or data not given.
W.T. Schaller, analyst.

Constituent	Analysis	Hydrogen equivalents			Molecular ratios	
SiO_2---------	35.96		0.596—4.00		0.596—12.00	
B_2O_3--------	10.61	---	.151—1.01		.151—3.03	
Al_2O_3-------	33.28	1.954			.326	6.63
Ti_2O_3-------	.36	.005			.003	
FeO--------	11.04	.307			.153	
MnO--------	.13	.004			.002	
CaO--------	.42	.015	2.897—19.44		.008	5.73
MgO--------	3.48	.174			.087	
K_2O---------	.00	---			---	
Na_2O--------	2.16	.070			.035	
H_2O--------	3.31	.368			.184—3.72	
F------------	.00				---	
Total---	100.75					

8. Miscellaneous localities.

The remaining tourmalines considered in this report have already been

described, and such properties as are available are taken to supplement the original descriptions already given. As the determinations are all found in the literature, only such values are given in tabulated form as have already been used. These are all copied from the paper of Wülfing.

----- indicates that no values were obtained or no data available

Number (as used in this report)	Locality	c-axis	Density	ϖ	ε	$\varpi-\varepsilon$
8-----------------	de Kalb, NY	0.4513	3.05	1.633	1.614	0.019
9-----------------	Pierrepont ,NY	.4521	3.12	1.658	1.633	.024
10----------------	Hamburg	.4511	3.07	1.638	1.618	.020
11----------------	Brazil D.	---	3.20	1.662	1.633	.029
12----------------	Haddam	---	3.22	1.669	1.638	.031
13----------------	aMonroe	---	---	---	---	---
14----------------	aOrford	---	---	---	---	---
15----------------	Alabaschka	---	3.22	1.662	1.632	.030
16----------------	Auburn D.	---	3.21	1.666	1.637	.029

These two tourmalines, whose physical properties were not known (nos. 13 and 14), were selected as their analyses showed that they would help with no. 12, to fill a vacant space on the diagram of figure 102. Unexpectedly, all three came to nearly the same geographic place.

The molecular ratios of the analyses of these 9 tourmalines have been recalculated with the following results.

No.	Locality	Analyst	SiO_2	B_2O_3	Al_2O_3	$RO + R_2O$	H_2O
8----	de Kalb	Penfield and Foote	12.00	3.03	5.70	9.00	3.72
9---	Pierrepont	Riggs	12.00	2.94	5.08	9.75	3.93
10---	Hamburg	Riggs	12.00	3.06	5.82	9.90	3.96
11---	Brazil D.	Riggs	12.00	2.88	6.69	6.18	4.08
12---	Haddam	Riggs	12.00	2.94	6.36	6.90	4.17
13---	Monroe	Riggs	12.00	2.73	6.27	6.96	4.20
14---	Orford	Riggs	12.00	2.85	6.36	7.05	4.14
15---	Alabaschka	Jan. Kalb	12.00	2.67	6.75	5.73	4.05
16---	Auburn D.	Riggs	12.00	2.85	6.87	5.43	4.17

The general chemical formula for tourmaline.

Before studying the general formula for tourmaline, it will be well to test the formula proposed by Penfield and Foote by means of the new analyses given in this paper. From the values of the "hydrogen equivalent" calculated from the analyses, as already given, the tabulation below is prepared.

No.	Locality	Crystal color	SiO2	B2O3	Total hydrogen equivalent
1-	Elba	Pink	4.00	0.93	20.08
2-	Mesa Grande	Pink	4.00	.97	20.05
3-	Mesa Grande	Pale green	4.00	.99	20.37
6-	Ramona	Black	4.00	1.02	20.09
7-	Lost Valley	Black	4.00	1.01	19.44

The general formula proposed by Penfield and Foote; namely, $H_2OB_2Si_4O_{21}$ is, therefore, confirmed and definitely established.

The analyses of the tourmalines from both California and Elba likewise confirm the 4 : 1 ratio of SiO_2 to B_2O_3, as shown in the table, the average value of the ratio being 4.00 : 0.98.

The question as to the amount of water or water plus fluorine can now be considered. The ratios of the silica to the water plus fluorine for the sixteen analyses used in this report are as follows:

Analysts abbreviations: Schaller for W.T. Schaller Penf. & Foote for S. L. Penfield and A. E. Foote 134; Riggs for R. B. Riggs 136, and Jann. Kalb. for ?

Analysis No.	Analyst	SiO2	H20+ 1/2F	Difference from 4
1	Schaller	12.00	3.72	-0.28
2	Schaller	12.00	3.81	-0.19
3	Schaller	12.00	3.81	-0.19
4	Penf. & Foote	12.00	3.93	-0.07
5	Scharizer	12.00	4.71	+0.71
6	Schaller	12.00	4.02	+0.02
7	Schaller	12.00	3.72	-0.28
8	Penf. & Foote	12.00	3.72	-0.28
9	Riggs	12.00	3.93	-0.07
10	Riggs	12.00	3.96	-0.04
11	Riggs	12.00	4.08	+0.08
12	Riggs	12.00	4.17	+0.17
13	Riggs	12.00	4.20	+0.20
14	Riggs	12.00	4.14	+0.14
15	Jann. Kalb	12.00	4.05	+0.05
16	Riggs	12.00	4.17	+0.17

The average of the ratios, the value 4.71 percent of analysis No. 5-which value is doubtless too high-being omitted is 3.96%, which is very close to 4. However, in some analyses, in which the water was very carefully and accurately determined (for example No. 8 by Penfield and Foote), the amount found is considerably less than 4.00. It seems better, therefore, for the present, at least, to consider that only 3 parts of water are present in every tourmaline to 12 parts of silica and to reckon the

remainder of the water with the other bases. It may be proved in the future that 4 parts of water are always present; but the question is not one of very great importance for this report

Before entering into a discussion of a formula for tourmaline, a few words about the possibility of solid solutions of compounds (bearing no chemical analogy to the formula of tourmaline) will be considered. This refers only to the possible mixture of "nonisomorphous" compounds. The conditions of formation of tourmalines are such as to afford the maximum opportunity for complexity in composition. The pegmatite tourmalines were among the first minerals to form, when the greatest number of chemical elements for the growing crystal to select from were present in the magma. The chances of including (as solid solution) elements, which, either in kind or quantity, do not belong to the pure tourmaline, are also at a maximum. The great number of color variations observed are an indication of the readiness with which a forming tourmaline crystal will change in composition. A supposed homogeneous, mono-colored crystal, may, in reality, be very inhomogeneous but with nothing patent to indicate such variability. The tourmaline produced by metamorphic processes have, likewise, an abundance of elements to choose from; therefore, the resultant mineral in a similar way, apt to be very complex in composition.

Among the bases entering into the composition of the mineral are some that are present only in certain varieties and to a small extent. These variable and sparse bases are the ones that most naturally would be considered as entering in solid solution. Thus, lithia (Li_2O), lime (CaO), potassia (K_2O), and soda (Na_2O), which last, though present in every tourmaline analyzed, shows a rather varying percentage.

These bases are most naturally assumed to be dissolved as such salts as are most stable under the same conditions under which the tourmalines themselves were formed. Therefore, the compounds of these bases, most likely to be taken up by tourmaline in solid solution, are the following:

For lithia, spodumene $Li_2O \cdot Al_2O_3 \cdot 4SiO_2$

For lime, garnet $3CaO \cdot -Al_2O_3 \cdot 3SiO_2$

For potassia, orthoclase or muscovite, $K_2O \cdot Al_2O_3 \cdot 6SiO_2$

For soda, albite $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$

Let us examine the results obtained by considering these bases as present in tourmaline in the state of solid solution. The green tourmaline from Connecticut analyzed by Penfield and Foote has been chosen for examination.

The ratios of the analysis are given below, followed by the subtraction of the supposed solid solution compounds and the final result.

Constituent	Ratios	Albite	Spodumene	Garnet	Total solid solution	Remainder (tourmaline)
SiO_2	0.616	0.204	0.220	0.023	0.447	0.169
B_2O_3	.157					.157
Al_2O_3	.388	.034	.055	.008	.097	.291
FeO	.030					.030
MnO	.028				.028	.062
CaO	.023			.023	.023	---
MgO	.004					.004
Na_2O	.034	.034			.034	--
Li_2O	.055		.055		.055	---
H_2O	.202					.202

The result yields figures which themselves show the absurdity of the proposition. The formulation of the remainder (that is, the pure tourmaline) gives a compound with but little more SiO2 (molecularly) than B203; whereas, the ratio of 4 : 1 is accepted by all for tourmaline.

Another phase of the solid solution proposition would be that the bases are dissolved as such and not as compounds. This, however, would lead to conceptions for which we have no evidence whatever and which from this very nature are highly improbable, as the pegmatites in which these tourmalines are found always have an excess of the acid-silica.

The uniformity of the ratios of all the bases to the silica (the ratio 4 : 20)-(reducing the bases to their hydrogen equivalent) deduced by Penfield and Foote is likewise strong evidence against the conception of solid solution of compounds differing in type of formula from that of tourmaline. It will then be considered that all the components given in the analyses are essential parts of the tourmaline itself.

The variability of the composition of the mineral shows that it can only be considered as a mineral group composed of a number of components, and the object of an investigation is to detect and isolate these components. This is done of course, by considering the variations in composition and finding out in what direction the mutual replacement lies.

In order to facilitate study of the possible correlation between the properties of the different varieties of tourmaline and its chemical composition all available published results are given where in the determinations were made on material analyzed as nearly similar as possible to the tourmaline compound. Unfortunately these are only too few.

Two examples, Nos. 13 and 14, on which no physical properties were determined, were selected to fill out a vacant space on the diagram of figure 102 and unexpectedly their position, ·with that of No. 12, fell into nearly the identical place.

Below is given the molecular ratios, calculated from the analyses of the 16 tourmalines described in this report. Silica is taken as 12.00 and water as 3.00, the excess water being reckoned with the other bases in with RO, which, therefore, includes FeO, MnO, CaO, MgO, K2O, Li2O, Na2O, and H2O (excess over 3.0).

Molecular ratios of tourmaline analyses.

Tourmaline No.	SiO2	B2O3	H2O	Al2O3	RO
1----	12.00	2.79	3.00	8.16	2.58
2----	12.00	2.91	3.00	7.95	3.21
3----	12.00	2.97	3.00	7.98	3.66
4----	12.00	3.06	3.00	7.56	4.32
5----	12.00	2.31	3.00	7.71	5.43
6----	12.00	3.06	3.00	7.29	5.31
7----	12.00	3.03	3.00	6.61	6.45
16--	12.00	2.85	3.00	6.87	6.60
15--	12.00	2.67	3.00	6.75	6.78
11--	12.00	2.88	3.00	6.69	7.26
12--	12.00	2.94	3.00	6.36	8.07
13--	12.00	2.73	3.00	6.27	8.16
14--	12.00	2.85	3.00	6.36	8.19
8----	12.00	3.03	3.00	5.70	9.72
9----	12.00	2.94	3.00	5.10	10.68
10---	12.00	3.06	3.00	5.82	10.86

As can be clearly seen from this table there is a reciprocal variation in the value for Al2O3 and RO. If this variation is compensating, then the summation of the two should be a constant. In order to test this, there are given in the table below, the summation of the ratios of Al2O3 plus 1/3 RO (as molecularly three RO is equivalent to one (Al2O3).

Tourmaline No.	Al2O3 + 1/3RO	Tourmaline No.	A1203 + 1/3RO
1	9.02	9---	9.01
2	9.02	10---	9.11
3	9.20	11---	9.05
4	9.00	12---	8.99
5	9.52	13---	9.09
6	9.06	14---	8.94
7	8.76	15---	8.66
8	9.07	16---	9.44

These summations are nearly constant. The relationship can also be expressed graphically as a straight line. In figure 102 are plotted the values for Al2O3 and RO and, as can be seen, the points lie fairly well on a straight line. The water content of the blue-black tourmaline (No. 5) analyzed by Scharizer, is abnormally high, and if the value found be change to correspond with the average value of the remaining 15 analyses, the point representing its composition takes the place 5' (represented by an open circle in figure 102), which lies much nearer to the straight line.

From the diagram of figure 102 the end components of tourmaline can be determined. If we omit for the present the tourmaline from Elba. which as already

stated is abnormal in its properties, the two components of whose mixtures the mineral tourmaline is formed, are:

(1) $12SiO_2 \cdot 3B_2O_3 \cdot 8Al_2O_3 \cdot 3RO \cdot 3H_2O$

(2) $12SiO_2 \cdot 3B_2O_3 \cdot 5Al_2O_3 \cdot 12RO \cdot 3H_2O$
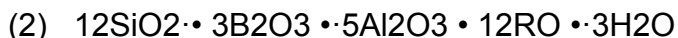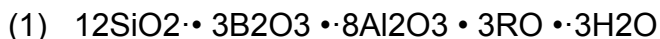
in which R = Fe , Mn ,Ca, Mg, K2, Na2, H2.

The first component is nearly represented by the pink so-called "lithia tourmaline" (No. 2) and the second by the magnesia, iron, and lime tourmaline from Pierrepont and from Hamburg (Nos. 9 and 10). The tourmaline from Elba (No. 1) is abnormal and to explain its composition, a third component must be introduced, which is still higher in alumina, and the only one available is

$12SiO_2 \cdot 3B_2O_3 \cdot 9Al_2O_3 \cdot 3H_2O$.
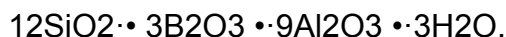
Figure 102 Relation between percentages of Al_2O_3 and RO tourmaline.

No tourmaline has been analyzed in which Fe, Mn, Ca, Mg, K, Na. and Li are entirely absent, and the third component is, therefore, only necessary to explain the composition of the tourmaline from Elba.
A set of formulas, instead of only two or three could be proposed, whose mixtures would yield tourmaline, as for example:

$12SiO_2 \cdot 3B_2O_3 \cdot 9Al_2O_3 \cdot 3H_2O$.

$12SiO_2 \cdot 3B_2O_3 \cdot 9Al_2O_3 \cdot 3RO \cdot 3H_2O$

$2SiO_2 \cdot 3B_2O_3 \cdot 7Al_2O_3 \cdot 6RO \cdot 3H_2O$

$2SiO_2 \cdot 3B_2O_3 \cdot 6Al_2O_3 \cdot 9RO \cdot 3H_2O$

$2SiO_2 \cdot 3B_2O_3 \cdot 5Al_2O_3 \cdot 12RO \cdot 3H_2O$

$2SiO_2 \cdot 3B_2O_3 \cdot 4Al_2O_3 \cdot 15RO \cdot 3H_2O$
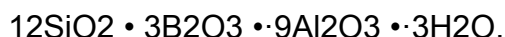
All tourmalines can be divided into two groups (explained more fully on page 000), according to the presence or absence of magnesium. The crystallographical and physical properties are not one linear function of the composition but two lines, which are not continuous. It, therefore, is necessary, in expressing the composition of tourmaline, to introduce a formula about midway between the two components already given, and this is seen from the diagram of figure 102 to be

$2SiO_2 \cdot 3B_2O_3 \cdot 7Al_2O_3 \cdot 6RO \cdot 3H_2O$
.
We, thus, have three, or including the one required for the Elba tourmaline, four formulas, with which the composition of tourmaline can be expressed. In all these formulas, however, the bases of the type FeO and Na_2O are united under the general symbol RO and this must now be expressed in terms of the particular elements concerned.

For tourmalines approximating to the formula

$2SiO_2 \cdot 3B_2O_3 \cdot \cdot 8Al_2O_3 \cdot \cdot 3RO \cdot 3H_2O$

the bases grouped together under RO are essentially three--namely Li_2O. Na_2O, and H_2O (that is, the excess of water over the 3 molecules). Minor constituents are FeO, MnO, CaO, K_2O, and F_2. The individual formulas required, therefore, to express the composition of the lithium tourmalines, are, including the one required for the Elba tourmaline but neglecting the minor constituents like (FeO, etc.), four in number as follows:

(1) $12SiO_2 \cdot 3B_2O_3 \cdot \cdot 9Al_2O_3 \cdot \cdot 3H_2O$

(2) $12SiO_2 \cdot 3B_2O_3 \cdot \cdot 8Al_2O_3 \cdot \cdot 3Li_2O \cdot 3H_2O$

3) $12SiO_2 \cdot 3B_2O_3 \cdot \cdot 8Al_2O_3 \cdot \cdot 3Na_2O \cdot 3H_2O$

4) $12SiO_2 \cdot 3B_2O_3 \cdot \cdot 8Al_2O_3 \cdot \cdot 3H_2O \cdot 3H_2O$

Should the water content of all tourmalines be eventually proved to be in the ratio of 4 : 12 to the silica, instead of 3 : 12, as here assumed, then formula 4 (above) would not be necessary. But it is assumed for the present that the maximum amount of water that must be present is in the ratio of 3 : 12.

For the magnesian tourmalines, the bases required by the general expression RO are MgO, FeO, CaO, Na_2O, and H_2O. It is to be noted that the soda content decreases with the alumina. Thus, in the analyses of Riggs, the five with the lowest soda percentages (the same holds true for potassia) are also lowest in alumina, as is seen in the following tabulation:

Locality	Minimum alumina	TiO2	Minimum alkalies	
			Na2O	K2O
Stony Point	30.49	0.40	1.76	0.15
Gouverneur	27.79	1.19	1.72	0.16
Pierrepont	25.29	0.55	1.51	0.20
De Kalb	28.87	0.12	1.39	0.18
Hamburg	28.49	0.65	0.94	0.18

It would seem, therefore, as if the soda present in these magnesium tourmalines could be ascribed to the soda formula given under the lithium tourmalines, but a calculation of the analyses shows that this is not possible and that a soda component of the magnesium type must be assumed.

The formula with H_2O in place of RO is only required if the ratio of water to silica be taken as 3 : 12.

The formula required therefore for the magnesian tourmalines are five in number and as follows:

$12SiO_2 \cdot 3B_2O_3 \cdot \cdot 5Al_2O_3 \cdot \cdot 12MgO \cdot 3H_2O$
$12SiO_2 \cdot 3B_2O_3 \cdot \cdot 5Al_2O_3 \cdot \cdot 12FeO \cdot 3H_2O$
$12SiO_2 \cdot 3B_2O_3 \cdot \cdot 5Al_2O_3 \cdot \cdot 12CaO \cdot 3H_2O$

12SiO2 • 3B2O3 •·5Al2O3 •·12H2O • 3H2O
12SiO2 • 3B2O3 •5Al2O3 •·12Na2O • 3H2O
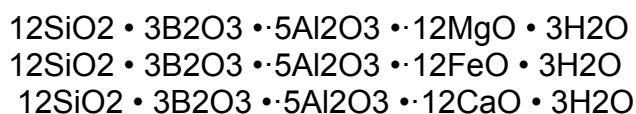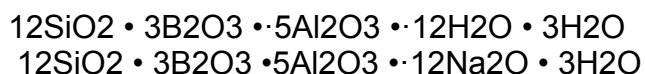
Correlation of properties with chemical composition.

General statement.

It has just been shown that the mineral tourmaline must be considered as a mixture of (a rather large number of) components, none of which have so far been found in nature nor produced artificially in the laboratory. The properties of these components are unknown. An attempt to correlate the properties of tourmaline with the variation in chemical composition is, therefore, at once confronted by the difficulty of not knowing the properties of the components themselves. With such a large number of components as tourmaline possesses, moreover, the properties, as determined on the natural crystals (mixtures of n components, n being generally large), should not be continuous functions, as the introduction of a single component (for example, 12SiO2 • 3B2O3 •5Al2O3 •·12CaO • 3H2O) may cause a considerable change in the properties both in direction and in amount.

Not withstanding the uncertainties just mentioned, it is possible to trace a variation in the properties of tourmaline and in a measure to correlate them with the chemical composition.

A general consideration of all tourmalines shows that each one may be placed in one of two groups, according to whether or not the element magnesium is absent or present. In many analyses where especial precautions were taken to select pure crystals, where the chemicals used were tested quantitatively for their impurities, and where the analyses were conducted in platinum ware as much as possible, the amount of magnesia has been found to be very small, practically nil.

The classification just given is arbitrary, but there are a number of circumstances to justify it. In the occurrences and associations of the mineral the division is a logical one.

The magnesium-free tourmalines occur in granitic pegmatites and have as associates quartz, albite, orthoclase, microcline, muscovite, garnet, and often lepidolite, beryl, and spodumene. The tourmalines included here are the blue-black ones, which have a high iron content, the blue indicolites, and the green-red and colorless ones, which form the so-called "lithia tourmalines." The only characteristic chemical feature of these tourmalines is the absence of magnesium.

The magnesium tourmalines, on the other band, are found rarely in pegmatites (the magnesian content being generally small) but are common in metamorphosed rocks, such as schists, altered limestones, shales, and the common associates are such minerals as quartz, biotite, phlogopite, augite, plagioclase feldspars, and tremolite. In color, they are generally black or brown, rarely white or colorless.

In making a correlation of the properties of tourmaline with its chemical composition, the question as to what chemical basis to use at once comes up. In figure 102 it was shown diagrammatically that there is a reciprocal relation between the Al2O3 and the RO. As the Al2O3 is but a single component (the amounts of Ti2O3 present being very small), and as the RO consists of numerous components, the best basis to use is the amount of Al2O3. The percentage values obtained in the analyses may be used directly as the percentages of Al2O3 reach a maximum in the iron+magnesium-free lithia tourmaline and a minimum in those varieties highest in magnesium, iron, and calcium.

Density.

The values for the density described in the earlier part of the report and not repeated here are shown graphically in figure 103. The specific gravity of the magnesium-free tourmalines shows a gradual increase, corresponding to the decrease in Al_2O_3 and the increase in FeO, as the other components of RO do not vary much except in the tourmalines richest in iron in which lithium is practically absent. The variation is expressed diagrammatically in the upper line of figure 103. The lower line represents the decrease in density corresponding to the decrease of Al_2O_3),and molecularly in the increase of the RO ratio, as this becomes increasingly greater in MgO with its low molecular weight. The minimum density of the magnesium tourmaline is only a little higher than the lowest value of the magnesium-free tourmaline. Tourmaline No. 1 (from Elba) has an abnormal position as it does in all the parts of figure 103. This is doubtless related to the unusual composition in that the extra components $12SiO_2$ • $3B_2O_3$ •$9Al_2O_3$ •·$3H_2O$ enters into the composition of the mineral. Tourmaline No. 9 (Pierrepont) likewise abnormal in position in the other parts of figure 103, probably also contains an extra unusual "chemical component." Except for No. 1 and 9, the position shown in figure 103, falls fairly well on two lines, which could well be united into a single curve, but the straight line is preferred, as this more clearly shows whether the variation is in direct correlation with the composition.

Figure 103 Relations of densities to composition, tourmaline.

The three densities to be specially noted for tourmaline may be stated in tabular form for emphasis:

Tourmaline type	Density	Degree of density
Magnesium-free	3.00-3.05	Minimum
	3.20-3.25	Maximum
Magnesium-bearing	3.20-3.25	Maximum
	3.05	Minimum

c - axis.

Unfortunately the available values for the c axis that can be correlated with the chemical composition are very few, and, in fact, for the magnesium tourmaline only three, and one of these is the abnormal tourmaline from Pierrepont. The values used were described earlier in this report and are plotted in figure 104. The lowest values are for the Elba and the pink lithium tourmalines, the highest for the iron-rich variety though only one such value is available and this is not certain, see page 000), and the magnesium tourmalines are again lower but not so low as the lithium tourmalines. The variations in the c-axis are similar in kind and approximately in value to the variations in density. Many more determinations are required, however, to show definitely in what direction the variation takes place.

Figure 104 Relation of c-axis to composition, tourmaline.

Optical properties.

Similar plottings of the values of ω and ε and of (ω - ε), show, as illustrated in figure 105, that the values for the lithium and the magnesium tourmaline are nearly alike and represent minimum values. The highest values are those belonging to the tourmalines of intermediate formulas, those richest in iron.

Figure 105 Relation of refractive indices to composition, tourmaline.

Conclusion

The investigations of the chemical composition of the common mineral tourmaline up to 1899 were so well summarized by Penfield and Foote[146] that it is unnecessary to repeat the formulas proposed. On the basis of two new analyses and by a recalculation of the old analyses, Penfield and Foote mentioned concluded that all tourmalines are derivatives of the acid $H_{20}B_2Si_4O_{21}$, and in a later paper Penfield[147] strenuously upheld his theory that "the empirical formula of the tourmaline acid must be $H_{20}B_2Si_4O_{21}$·"

In 1912 the ·writer published[148] a number of analyses of California tourmalines, which fully substantiated Penfield's formula. The year following two of Wülfing's students published doctorate theses on the tourmaline group. Reiner[149]145 proposed a third and new formula for iron-tourmaline and, citing Wülfing's earlier two formulas, suggested that all tourmalines were formed of mixtures of the three molecules:

$Si_{12}Al_{16}B_6Na_4H_8O_{63}$
$Si_{12}Al_{12}B_6Fe_8H_8O_{63}$
$Si_{12}Al_{10}B_6Mg_{12}H_6O_{63}$
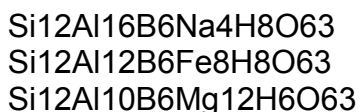
The same year Becht[150] published descriptions of magnesia tourmalines, which agreed with Wülfing's theory of the composition of tourmalines.

The same year Vernadsky[151] discussed the composition of tourmaline and concluded that Penfield's empirical formula must be considered established and suggested the series:

Elbaite series	$H_2Al_6B_2Si_4O_{21}$
Belbaite series[152]	$H_{14}Al_2B_2Si_4O_{21}$

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[146] Penfield, S.L and Foote, H.W., On the chemical composition of tourmaline: Am. Jour. Sci., 4th ser., vol. 7, p. 97, 1899.

[147] Penfield, S.L, On the interpretation of mineral analyses: A criticism of recent articles on the constitution of tourmaline: Am. Jour. Sci., 4th ser., vol. 10, p. 19, 1900.

[148] Schaller, W.T., Beitrag zur Kenntnis der Turmalingruppe: Zeitschr. Kryst. Min., vol. 51, p. 321, 1912.

[149] Reiner, P. Beitrlge zur Kenntnis der Turmalingruppe: Inaug. Dissertation Heidelberg. 1912. Verbandl. Naturbist. Med.-Ver. Heidelberg. N.F., vol. 12, p. 262, 1913.

[150] Becht, K. Beitrlge zur Kenntnis der Magnesia-Tourmaline: Inaug. Dissertation Heidelberg. p. 75, 1913.

[151] Vernadsky, W., Ober die chemiscbe Forme!der Turmaline: Zcitschr. Kryst. Min., vol. 53, p. 273, 1913.

[152] Most readers will be familar with the mineral-elbaite. However, the terms "belbaite" and "kalbaite" are very obscure., having been proposed by Vernadsky as

Kalbaite series $H_8Al_4B_2Si_4O_{21}$

in which the bases (lithium, iron, magnesium, etc.) are grouped with the hydrogen. Clarke[153] still adheres to his old formula for tourmaline, $H_{58}B_6Si_{12}O_{62}$·and suggests compounds of the type

$Si_{12}Al_{18}B_6Na_4O_{62}$
$Si_{12}Al_{18}B_6Li_4O_{62}$
$Si_{12}Al_{16}B_6Na_4H_6O_{62}$
$Si_{12}Al_{10}B_6Fe_8H_{12}O_{62}$
$Si_{12}Al_{10}B_6Ca_{18}H_{12}O_{62}$
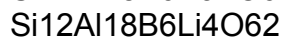
to explain the composition of the tourmalines. The discrepancies between the analyses and the theoretical composition calculated from his formulas are explained away by the assumption that fine grinding has materially changed the water content of the tourmalines. The analyses made by the writer do not substantiate the formulas of Clarke, as can be clearly shown by the following table. The ratio of SiO_2 : B_2O_3: Total hydrogen-equivalent of Clarke's formula is 4 : 1 : 19 1/3.

Comparison of ratios of analyses with Clarke's formula for tourmaline.

Locality and color	SiO2	B2O3	Total hydrogen equivalent		
			Found	Clarke's formula	Penfield's formula
Elba, pink	4.00	0.93	20.08	19.33	20.00
Mesa Grande, pink	4.00	0.97	20.05	19.33	20.00
Mesa Grande, green	4.00	0.99	20.37	19.33	20.00
Ramona, black,	4.00	1.02	20.09	19.33	20.00
Lost Valley, black	4.00	1.01	19.44	19.33	20.00
- Average------------	---	---	20.01	19.33	20.00

The formulas proposed by Wülfing, Vernadsky, and the writer are all referable to Penfield's empirical formula $H_2O·•$ $B_2Si_4O_{21}$ and, moreover, are practically identical, as the following table shows:

Formulas proposed for tourmaline.
 ----- indicates no data for the value. R =Na2, Li2, H2, Fe, Ca, Mg. etc.)

---

the names for two of three hypothetical series of tourmaline that were soon rejected, and. as a result, never were used to any extent among mineralogists.

[153] Clarke, F.W., The constitution of the natural silicates: U.S. Geol. Survey Bull. 588, p. 000, 1914.

Schaller	Wülfing	Vernadsky
$12SiO_2 \cdot 3B_2O_3 \cdot 9Al_2O_3 \cdot H_2O$	---	$12SiO_2 \cdot 3B_2O_3 \cdot 9Al_2O_3 \cdot 3RO$
$12SiO_2 \cdot 3B_2O_3 \cdot 8Al_2O_3 \cdot 3RO \cdot 3H_2O$	$12SiO_2 \cdot 3B_2O_3 \cdot 8Al_2O_3 \cdot 2Na_2O \cdot 4H_2O$	---
$12SiO_2 \cdot 3B_2O_3 \cdot 7Al_2O_3 \cdot 6RO \cdot 3H_2O$	---	---
$12SiO_2 \cdot 3B_2O_3 \cdot 6Al_2O_3 \cdot 9RO \cdot 3H_2O$	$12SiO_2 \cdot 3B_2O_3 \cdot 5Al_2O_3 \cdot 8FeO \cdot 3H_2O$	$12SiO_2 \cdot 3B_2O_3 \cdot 6Al_2O_3 \cdot 12RO$
$12SiO_2 \cdot 3B_2O_3 \cdot 5Al_2O_3 \cdot 12RO \cdot 3H_2O$	$12SiO_2 \cdot 3B_2O_3 \cdot 5Al_2O_3 \cdot 12MgO \cdot 3H_2O$	---
$12SiO_2 \cdot 3B_2O_3 \cdot 4Al_2O_3 \cdot 15RO \cdot 3H_2O$	---	---
$12SiO_2 \cdot 3B_2O_3 \cdot 3Al_2O_3 \cdot 18RO \cdot 3H_2O$	---	$12SiO_2 \cdot 3B_2O_3 \cdot 3Al_2O_3 \cdot 21RO$
$12SiO_2 \cdot 3B_2O_3 \cdot 2Al_2O_3 \cdot 21RO \cdot 3H_2O$	---	---
$12SiO_2 \cdot 3B_2O_3 \cdot 1Al_2O_3 \cdot 12RO \cdot 3H_2O$	---	---
$12SiO_2 \cdot 3B_2O_3 \cdot 0Al_2O_3 \cdot 27RO \cdot 3H_2O$	---	---

The individual formulas of Vernadsky would be as follows:

Elbaite series	$NaHAl6B2Si4O21$
	$LiHAl6B2Si4O21$
	$H2Al6B2Si4O21$
	$Li2Al6B2Si4O21$
	$Na2Al6B2Si4O21$

Kalbaite	$H4Fe4Al4B2Si4O21$
	$H4Mg4Al4B2Si4O21$
	$H4Ca4Al4B2Si4O21$

Whatever the exact formula of the lithium end of the tourmaline series may be, all authors are agreed that these lithium tourmalines do represent one end of the series.

Wülfing writes their formula as $12SiO2 \cdot 3B2O3 \cdot 8Al2O3 \cdot 2(Na,Li)2O \cdot 4H2O$ and Vernadsky as $12SiO2 \cdot 3B2O3 \cdot 9Al2O3 \cdot 3(Na,Li,H)2O$.

The analyses of pink tourmalines given in this report agree closely with Wülfing's formula as shown below:

Wülfing's formula:
$12SiO2 \cdot 3.00B2O3 \cdot 8.00Al2O3 \cdot 2.00(Na,Li)2O \cdot 4.00H2O$

Elba, pink tourmaline:
$12.00SiO2 \cdot 2.79B2O3 \cdot 8.16Al2O3 \cdot 1.78(Na,Li)2O \cdot 3.72H2O \cdot 0.08RO$

Mesa Grande, pink tourmaline
$12.00SiO2 \cdot 2.91B2O3 \cdot 7.95Al2O3 \cdot 1.88(Na,Li)2O \cdot 3.81H2O \cdot 0.52RO$

Wülfing's formula may, therefore, be assigned to elbaite as, at present, best representing its composition.

It is desirable, therefore, to recognize more clearly this lithium-end member of the tourmaline series as a definite species, and it is hereby proposed definitely to assign to it Vernadsky's name elbaite

The correlation of the physical properties of tourmaline with its chemical composition (p. 000) shows that those tourmalines with about 35 to 36 percent alumina reach a maximum in the value of the .c- axis, of the density, of the refractive indices, and of the birefringence. Chemically, these tourmalines show the highest

percentage of FeO, and they are generally spoken of as iron-tourmalines. The black tourmaline from Ramona represents this tourmaline more closely than any of the others from California that were analyzed by the writer. By calculating from the analysis, it was found that after the elbaite molecule

12SiO2 • 3B2O3 • 8Al2O3 • 2(Na,Li)2O • 4H2O had been deducted, the composition of the remainder was closely expressed by the formula: 12SiO2 • 3B2O3 • 7Al2O3 • 5FeO • 4H2O. For this compound the name schorlite is proposed. It is found that the black tourmaline from Ramona is composed of about 73 percent of schorlite and 27 percent of elbaite, as the following comparison shows:

Comparison of analysis of Ramona tourmaline with calculated values.

Black tourmaline from Ramona		Calculated for 73 percent schorlite + 27 percent elbaite	Difference
Analysis reduced			
SiO_2-------	35.19	35.42	-0.23
B_2O_3------	10.42	10.28	+0.14
Al_2O_3----	36.21	36.42	-0.21
FeO-------	12.75	12.63	+0.12
Na_2O------	1.92	1.74	+0.12
H_2O-------	3.51	3.51	+0.18
Total-	100.00	100.00	0

Elbaite.

Nomenclature.

The name elbaite includes those members of the tourmaline group that have a high percentage of Al2O3 and Li2O and practically no FeO, CaO, or MgO. Therefore, elbaite is one end of the series of which the various tourmalines are members. The discussion of the derivation of this end member has been given in the section on the tourmaline group.

Occurrence.

Elbaite is widespread in its occurrence in the California field, and the total number of localities is doubtless much larger than the list of producing mines, as small amounts of elbaite have been encountered in pegmatites whereon no development work had been done.

Elbaite is found only in the middle part of pegmatite dikes. It is an essential mineral of the pay shoot and is the gem stone most sought for. It occurs intimately associated with albite, lepidolite, and quartz, with which minerals it is contemporaneous in time of formation. It is also closely associated with many of the other minerals of the pay shoot-microcline, muscovite--and the relation of elbaite to them is given in the separate descriptions of these minerals. The majority of the elbaites belong to one general period of formation, but, occasionally, specimens are

found that indicate that later generations have formed locally. These later generations consist of minute and very slender pink crystals. The different modes of occurrence of the gem elbaite have been given in the description of the middle part of the dike, on pages 000 to 000.

A very unusual form of occurrence is exhibited in Plate XXXII F wherein is shown elbaite crystal completely enclosed in a second rubellite crystal.

Isolated, single large crystals or a group of a few large crystals (Plate I) united together with quartz and feldspar are very abundant. More rarely a number of nearly parallel but slightly divergent individuals are united in such a way as to produce an apparent single large crystal (Plate XXIV). Large compact masses of minute elbaites are also found; these may form either a solid mass, as the blue indicolites from the Katerina mine, or they may form a cavity into which larger crystals project (Plate VII A).

Crystallography.

Values of c axis.

The crystallographical element, the c axis, is given an average value of 0.448. The measurements on which this value is based are as follows:

Measurements of elbaite crystals for determination of c axis.

Color	Locality	$\rho\{10\bar{1}1\}$	c axis
Pink	Pala	27°55'	
Pink	do.	26°52'	0.44826
Pink	do.	27°18'	
Pink	Mesa Grande	six faces {2131}	.4475
Green	Mesa Grande	27°22'	.4482
Do. (?) [a]	do. (?) [a]	26°66'	.4495

a Schaller listed the last entry without indicating the color or the locality. With an understanding of Schaller's writing and the data provided, the editors believe that this was another crystal from Mesa Grande.

Habit.

The crystals of elbaite are divided into four habits: (1) basal, with large, development of the base c {0001}; (2) rhombohedral, with large development of a rhombohedron; (3) scalenohedral, with a scalenohedron the prominent terminal form; and (4) distorted crystals. A very few crystals of the basal habit were seen that were as thick as they were high, but most of them are elongated in the direction of the c axis. The first three habits are illustrated in Plate XXXII A, B, C.

The crystals with a prominent base show either this form alone, as the large green crystals from Ramona (Plate XXVIII G) or else the base is modified by small faces of rhombohedrons. Pink crystals capped by a light green (either on c alone or on c with very small faces of e and r) are abundant, especially at Mesa Grande. A common type with a red termination is c, o (large) and r (minute) and the other end to show c, e (large) and r (minute). The combination cor has bright faces;

the o faces frequently are unequal in size, the r faces are mostly line faces. The combination c r e is usually dull. Numerous achroite crystals, some of which are white without a tinge of pink or green. show large dull faces of c as the only end form. The common combinations for crystals of the basal habit are shown in figure 106.

Forms and angles.

The forms observed on the elbaite crystals are the common ones: c {0001}, m {10$\bar{1}$0}, a {11-20}, r {10$\bar{1}$1}, e {02-21}, {077-2}, s {21$\bar{3}$1}, and u {31-41}, and the rare form {17.0.17 .4}.

FIGURE 106.-Common combinations on tourmaline crystals of the basal habit.

The rhombohedral habit is determined by large faces of r, more rarely of o, with the base and other rhombohedrons small. The colors are mostly green and blue. The common combinations are r, o c r, r e, or, co, cor, c e r, and are shown in figure 107.

FIGURE 107.-Common combinations on crystals of rhombohedral habit.

The scalenohedral crystals have their habit determined by the forms: t (green), t with r (colorless or pink), t with x (pink), and rarely x with other forms (pink). The common combinations on crystals of the scalenohedral habit are shown in figure 108.

FIGURE 108.-Common combinations on crystals of the scalenohedral habit.

The fourth habit includes distorted crystals, which necessarily embrace a wide diversity of forms. The distortion is due to suppression of one or more of the faces belonging to a form with consequent peculiar shape of resulting crystal or to an unequal development of the faces of a form that may yield very unsymmetrical or falsely symmetrical forms. The distortion may also be a vectoral one; the crystals are elongated to hair like forms, or are flattened very thin parallel to some face in the prism zone, or have been broken and the fracture healed by bands of fibrous tourmaline needles.

More complex combinations than those mentioned are but rarely found, as the California tourmalines are poorly developed for forms. Some of those showing a richer combination of forms are described in the following section.

Description of crystals.

The pale-green crystals from the Stewart mine, at Pala, on which the axial ratio was determined, show a variation in habit between two extremes. On one extreme the rhombohedron ζ {077-2} is largely developed and the crystal has the appearance shown in figure 109. On other crystals the rhombohedron is small and the other forms notably t or r become equally developed, and the crystal has the appearance shown in figure 110.

FIGURE 109.-First rhombohedral type of pale-green tourmaline from the Stewart mine, Pala.

FIGURE 110.-Second type of the pale-green tourmaline from the Stewart mine, Pala.

Combinations

The combinations observed, not including the rounded prism zone, on available material from the different localities are as follows:

        Pala ------   c r t ξ E
        Pala-------   c t
        Pala ------   c t r
        Pala ------   c t ξ r e

        Mesa Grande c r e
        Mesa Grande c o r
        Mesa Grande c o r e
        Mesa Grande c t r

        Ramona   c t
        Ramona   c t r

Physical properties.

Density.

The density determinations made on various elbaite crystals are as follows:

Density determinations on elbaite.

Locality	Color	Density range	Density
Himalaya mine, Mesa Grande a	Pink	3.033-3.039	3.04
Himalaya mine, Mesa Grande	Pink		3.04
Naylor mine, Oak Grove--------	Pink		3.03
Stewart mine, Pala --------------			3.02
Himalaya mine, Mesa Grande a	Pale green	3.040-3.046	3.04
Stewart mine, Pala --------------	Pale green		3.05
Pala Chief mine, Pala ----------	Pale blue	3.062-3.067	3.06
Tourmaline Queen mine, Pala	Pale green	3.082-3.089	3.09
Little Three mine, Ramona b	Light olive-green	3.101-3.102	3.10
Little Three mine, Ramona c	Dark olive-green	3.102-3.110	3.11
Pala Chief mine Pala	Blue	3.110-3.114	3.11

        a Material analyzed.
        b Outer shell of crystal.
        c Inside of crystal.

The density of pure elbaite is near the minimum value found and may be given as 3.02. All these determinations were made on perfectly transparent material free from cracks. That the material must be free from cracks (which will enclose air) is shown by the low value obtained (2.99) on pink tourmaline from Pala, which had a few small cracks.

Heat effects.

Elbaite is infusible before the blowpipe and does not give a lithium flame. In its lack of fusibility, elbaite differs greatly from schorlite. The admixture of more and more of the schorlite molecule increases the fusibility, so that the dark-green tourmaline from Ramona, for example, is fusible in thin splinters though not nearby so readily as the black schorlite from the same locality.

Such of the California tourmalines as were tested for their piezoelectric effects followed the regular law in that the end showing the richest combination (c t r e, c r t ζ e, etc.) was the antilogous end; whereas the analogous end was generally terminated only by the base c or c with r and e poorly developed.

Optical properties.

Color.

Elbaite is colorless, or its body color is red, yellow, green, blue, or some combination of these colors. Crystals have been observed that are either colorless or white, pink, yellow, green, or blue throughout their entire extent; others are polychromatic, that is, they show more than one color in the same crystal. The two colors either lie in horizontal relation to each other, the contact line being parallel to some crystal face (the base if horizontal, the rhombohedron if inclined) or they penetrate each other cone-fashion, a horizontal cross section of the crystal showing a concentric color arrangement. Two very common phases where the colors lie in horizontal relation to each other are shown in figure 111.

FIGURE 111.-Color combinations in elbaite.

The commonest cone-fashion arrangement of color is a black core and a pink exterior shell, as shown in figure 111. The color arrangement is also concentric in basal cross section without core-fashion structure, but in this case there are evidently two generations of tourmaline, the one forming a secondary shell around the other. Such a formation is shown in Plate XXXII G, where a white elbaite is surrounded by a thin shell of black schorlite. The two kinds of color arrangement occur together on the same crystal, as is shown by a specimen from the Pala Chief mine, at Pala, and illustrated in figure 111. The color combination is also very irregular at places, and, again, it may follow certain crystallographical directions, as the three lines of deeper red that are seen in some basal sections and, which on some colorless crystals, follow the rhombohedral intersection edges. The color and schemes of color also repeat themselves or alternate and yield a most bewildering array of colors and shades. Thus, on a transparent crystal from the Himalaya mine, at Mesa Grande, the following colorings all very delicate and imperceptibly grading into one another, were noticed. The crystal measured 127 by 11-1/2 by 7-1/2 mm and weighed 26 grams. The top of the crystal (c small, bright; r large, dull) was pink (6 mm); then came; colorless (12 mm), pale green (27 mm), very pale blue (33 mm), very pale lilac (52 mm}, colorless (67 mm), pale green (127 mm), which extended to the lower termination (c large, dull; e and r, small, dull). It is believed that the pink was the last to form; it is to be noted then that the size of each color gradually decreased. The equilibrium between the amounts of green pigment (iron) and red pigment (manganese) must have been very delicate. At the beginning, the iron was in excess

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(green); then enough manganese separated out to exactly balance and neutralize the iron (colorless); the manganese was then slightly in excess (lilac); and later the iron again acquired its preponderance (blue and green); only to be again overtaken by the manganese and neutralized (colorless); and finally the manganese remained in excess (pink), until the end of the crystallization of the elbaite crystal. These relations are diagrammatically shown in figure 111. Another multicolored crystal described by Sterrett[154] had the following colors:

Beginning with the lower end there is a layer of fine green; above this, bluish green fading into light rose color: then sea- green passing into smoky brown or brownish green; on this comes a cap of dark pink, appearing scarlet by reflected light.

Refractive Indices.

Refractive indices of pink crystals from Mesa Grande.

Crystal	ω	ε
No. 1.	1.648	1.628
No. 2	1.646	1.628
No. 3	1.645	1.628
No. 4.	1.647	1.629
No. 5.	1.648	1.628

Pleochroism.

The pleochroism noted on the elbaite crystals is as follows:

Body color	Locality	ω, parallel c axis	ε normal c axis
Pink	Mesa Grande	Pink	Colorless.
Green	Pala	Green	Pale green
Blue	Pala	Blue	Pinkish

Chemical properties.

Quantitative composition.

An attempt has been made to show in the discussion of the tourmaline group, that the tourmalines rich in alumina and lithia represent one of the end products, whose formula approaches closely to one of the end products, whose formula approaches closely to $12SiO_2 \cdot B_2O_3 \cdot 8Al_2O_3 \cdot 3(Li,Na,H)_2O \cdot 3H_2O$, which is the same in type as Wülfing's formula, $12SiO_2 \cdot 3B_2O_3 \cdot 8Al_2O_3 \cdot 2Na_2O \cdot 4H_2O$

Alteration.

Pink crystals of elbaite from the Stewart mine, at Pala, show all stages of alteration to a clayey pink mass allied to the substance called halloysite. Some of the material retains the crystal shape and striations of the tourmaline but is so soft

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[154] Sterrett, D.B., Tourmaline from San Diego County, California: Am. Jour. Sci., 4th ser., vol. 17, p. 452, 1904.

that it can be readily cut with a knife. In parts of the pegmatite where movement in the rock mass has taken place (probably caused by the expansion resulting from the alteration of potash feldspar to kaolin), the altered pink tourmalines have been squeezed, and the material rearranged so that it now represents a pink clayey mass in which no trace of the original structure of the tourmaline crystals remains. This material, when placed in cold water, readily falls to pieces whereas, the soft pseudomorphous crystals, though they are so soft, that they can be ground to powder by hand, do not break down in water, not even when heated for several hours in boiling water.

Two different samples of these altered elbaites were analyzed, one more altered than the other. The analyses are given below, to which are added for comparison the analysis of similar pink elbaite (from Mesa Grande) and the analysis of the final alteration product, halloysite.

Analysis of tourmaline and its alteration products.
W.T. Schaller, analyst

Material--	Unaltered pink elbaite	Partly altered pink elbaite	Much more altered pink	Resultant clay, final alteration product
Locality---	Mesa Grande	Pala, Stewart mine	Pala, Stewart mine	Pala, Stewart mine
SiO_2-------	35.57	36.98	37.05	43.62
B_2O_3------	10.65	[a]8.36	[b]1.84	- - -
Al_2O_3-----	42.18	43.69	4.25	35.55
Na_2O-------	2.05	2.02	1.06	.19
Li_2O-------	1.92	1.28	1.27	.23
H_2O^+------	3.38	4.67	10.81	12.25
H_2O^--------	.00	1.16	.83	6.63
F------------	.39	- - -	- - -	- - -
FeO-------	.19	- - -	- - -	[c].21
MnO-------	.24	trace	trace	.26
CaO-------	1.20	.25	.22	1.02
MgO-------	none	- - -	.10	.19
K_2O-------	none	2.29	1.95	.03
Total--	[d]99.60	100.72	99.38	100.18

a Not determined by the writer. The value by difference would be 7.66 percent. Chapin and Wherry (Jour. Am. Chem. Soc., vol. 30, p. 1687, 1908.) determined it as 9.10 percent. The average, 8.38 percent, is used here.

b Not determined by the writer. The value by difference would be 2.46 percent. Chapin and Wherry (op. cit.) determined it as 1.21 percent. The average, 1.84 percent, is used here.

c Total iron as Fe_2O_3

d With 0.17 percent, due to excess of O, deducted

PLATE XXXII. Tourmaline and beryl.

A. Basal habit of tourmaline crystal. Colorless elbaite from the San Diego mine, Mesa Grande. See page

B. Rhombohedral habit of tourmaline crystal. Pink elbaite with green capping from the Pala Chief mine, Pala. The adhering crystals are lepidolite. See page

C. Scalenohedral habit of tourmaline crystal. Green elbaite from the Tourmaline Queen mine at Pala. See page

D. Two elbaite crystals with an adhering lepidolite crystal. See page

E. Bent elbaite crystal. In the Harvard University Mineralogical Museum (the A.F. Holden collection). See page

F. Elbaite crystal embedded in a larger one. The Harvard University Mineralogical Museum (the A.F. Holden Collection). See page

G. A later generation of schorlite (black) surrounding an earlier one of elbaite (white). Specimen presented by Mr. E. Schernikow of New York. See page

H. Tourmaline crystal completely covered with cookeite. See page

I. A similar crystal with a portion of the cookeite removed to show the interior tourmaline crystal. See page

A-I inclusive Natural size. D-I inclusive from the Himalaya mine, at Mesa Grande. A, B, C, D, G, H, I in the United States National Museum. J, K. Schorlite. (black tourmaline) crystals, partly altered to muscovite. See page, L, M, N. Similar crystals almost completely altered to muscovite See page, J-N, natural size, Little Three mine, Ramona. 0. Schorlite crystal altering to muscovite. Only the inner nucleus is still schorlite. Enlarged four times. Surprise mine, Ramona. See page, P. Pegmatite rock, Rincon. Shows schorlite crystals, (1) unaltered, (2) partly altered, and (3) completely altered to muscovite. The surrounding potash feldspar is unaltered, showing that the change from schorlite to muscovite was a magmatic alteration taking place before the feldspar was formed. Described on page, J-P, inclusive in the United States National Museum. Q. A group of well-developed beryl crystals associated with albite, tourmaline, lepidolite, and quartz. Two-fifths natural size. The American Museum of Natural History, New York City.

Schorlite.

Occurrence.

Schorlite, the black tourmaline with a high percentage of iron, is very widespread in its occurrence in the pegmatites and is abundantly present in every exposure studied.

Schorlite is abundant in the upper parts of the pegmatites, is rarer in the lower banded rock, and rather scarce in the middle part. Where schorlite is present in the middle part, it usually forms the lower core of a large tourmaline crystal, which is successively black, green, and red in color, grading from the black schorlite to the red elbaite. The associated minerals are, therefore, feldspar, muscovite, quartz, and garnet, schorlite not being a common associate of the minerals found only in the pay shoot.

All of these specimens are black or blue-black and opaque, except in thin splinters. They come from the upper and lower parts of the pegmatite, not from the middle part.

Density of schorlite.

Specimen No.	Locality	Density
1042----	Prospect No. 3, Pala Chief Hill, Pala	3.15
1033----	Tourmaline Queen mine, Pala	3.15
1008----	Pala	3.145
1027----	Tourmaline Queen mine, Pala	3.15
1036----	Tourmaline Queen mine, Pala	3.155
80-------	Coahuila, Riverside County	3.16
263-----	Coahuila, Riverside County	3.165
1009---	Pala Chief Hill, Pala	3.17
1038---	Pala Chief Hill, Pala	3.17
1021---	Tourmaline Queen mine, Pala	3.17
1011--	Pala Chief Hill, Pala	3.18
1031--	Tourmaline Queen mine, Pala	3.18
1029--	Tourmaline Queen mine, Pala	3.185
1013--	Ramona	3.185
1016--	Ramona	3.185

Crystallography.

Crystals of schorlite showing well-terminated faces are very rare. The forms of the prism zone are well developed, but otherwise crystal faces are seldom seen. A number of large schorlite crystals were obtained from the early workings of the San Diego mine. These showed either the base or the base with one or two rhombohedrons. Similarly, the terminated crystals from Ramona showed only the forms c, r, and e, in addition to those of the prism zone.

Physical properties.

Density.

The density of schorlite is approximately 3.2. The crystals from Ramona have a density of 3.22, and many other black iron-rich tourmalines have a recorded density of more than 3.2. The density of some schorlites sinks lower than 3.2, as appears in the following tabulation. This is owing to isomorphous admixture of small amounts of the elbaite molecule.

Specimen No.	Locality	Density
353----	Stewart mine, Pala	3.19
1039--	Pala Chief Hill, Pala	3.19
1034--	Tourmaline Queen mine, Pala	3.19
1012--	Ramona	3.15
298----	Coahuila, Riverside County	3.19
1041---	Ramona	3.19
1005---	Pala Chief Hill, Pala	3.195
262-----	Coahuila, Riverside County	3.20
1030---	Esmeralda mine, Mesa Grande	3.20
1018---	Pala Chief Hill, Pala	3.20
1014---	Tourmaline Queen mine, Pala	3.20
1020---	Pala Chief mine, Pala	3.205
1019---	Pala Chief mine, Pala	3.20
1015---	Stewart mine, Pala	3.20+
1010---	Ramona	3.20+
1026---	Pala Chief mine Pala	3.20+

Heat effects.

Schorlite is readily fusible and yields a black magnetic bead. When powdered schorlite is heated in a crucible it becomes brown, and the iron can now be extracted by treatment with HCl. In these reactions schorlite is very different from elbaite.

Optical properties.

Color.

Schorlite is black, in some specimens more of a blue-black. It is opaque as the term is generously used. In very thin splinters it is transparent, unless affected by the strong absorption.

Refractive indices.

The refractive indices were determined by the method of oil immersion on the sample analyzed. This specimen was found in the Surprise mine and gave the following values: ro = 1.67, s = 1.64. These values are very close to those obtained by Wiilfing as given on page 000. The birefringence 0.03, as well as the values for Bxo are considerably higher than the values of elbaite.

Pleochroism.

The pleochroism is very constant for all the schorlite from California investigated, and is as follows: ro = blue, s = purple. The absorption is very strong.

Chemical properties.

Quantitative composition.

The analysis of the schorlite from Ramona has already been given on page 000 and need, therefore, not be reproduced here. The composition distinguishes itself from other tourmalines in its high content of iron (more than 10 percent) and its low content of alkali lime and magnesia. Thus, it is essentially a hydrous borosilicate of aluminum and iron, but it has not yet been possible to assign a definite formula to the mineral.

Alteration.

Schorlite alters to muscovite; the occurrence has been previously noted from other localities. It is very well shown by numerous specimens from California. Plate XXXII O shows a schorlite crystal partly altered to muscovite, only a central core of black unaltered schorlite remaining. Similarly, more completely altered crystals of schorlite are shown in Plate XXXII J-P. A very interesting specimen is shown in Plate XXXII P. It is part of a first-group pegmatite consisting of a granular aggregate of feldspar and quartz, in which are several crystals of schorlite and plates of primary muscovite. Some of the schorlite crystals are completely altered to muscovite, others are partly altered, and still others are perfectly fresh and show no signs of any alteration. All three varieties lie embedded in the granular aggregate of unaltered orthoclase and quartz. The alteration of schorlite to muscovite must have been magmatic, and the changes as far as they went must have taken place before the solidification of the orthoclase and quartz that were molded around the altered and unaltered schorlites. The present appearance of the specimen showing the altered schorlite crystals embedded in unaltered orthoclase is rather unusual but can be explained as due to the processes outlined above.

PLATE XXXIII.
A. Elbaite and lepidolite, Stewart mine, Pala. The lepidolite constitutes the "lithium ore" mined.
B. Pink beryl crystal, Pala.
C. Altered lithiophilite. The flesh-colored mineral in the center is palaite; the surrounding brown is salmonsite; the black is manganite. The mixture of blue and yellow to the right is strengite and stewartite.

Beryl
Nomenclature.

Beryl was for a long time considered as a mineral of definite composition, whose formula was written $3BeO \cdot Al_2O_3 \cdot 6 Si$, until Penfield[155] showed that alkalies, especially lithium and caesium, and water were present in quantity and had to be reckoned with in considering the formula of beryl. After the presence of alkalies, and especially of caesium, had been confirmed in numerous beryls, the suggestion was

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[155] Penfield, S.L., On the occurrence of alkalies in beryl: Am. Jour. Sci., 3d ser., vol. 28, p. 25, 1884; (with D.N. Harper) On the chemical composition of herderite and beryl: bidem, vol. 32, p. 110, 1886.

made by Vernadsky[156] that all beryls were members of an isomorphous series of which one member was the caesium beryl. For this caesium beryl he proposed the name Worobieffite. Vernadsky interpreted the constitution of beryl by assuming the existence of the mica--or kaolin-nucleus, because the alteration of beryl yields muscovite or kaolin with separation of quartz. Beryl is, therefore, considered by him as the beryllium salt of the acid $H_2Al_2Si_2O_8$ or its analogues, and the general scheme for the composition of beryl is

$p = BeAl_2Si_4O_{12}$ Acid salt (A.S.) $BeSiO_3$
wherein $p = 1, 2, 3, ...,$ (A.S.) : $p < 2$ or$= 2$.
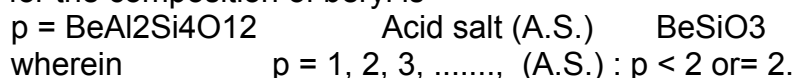
The beryl group consists then of addition products of the silicate groups to the beryllium salts of the alumino silicio acids and consists of isomorphous mixtures of the following:

1 - $2BeAl_2Si_4O_{12}$ $3 BeSiO_3$
                             Be_2SiO_4

2- $BeAl_2Si_4O_{12}$ BeH_2SiO_4
                             Cs_2SiO_3

3 - $BeAl_2Si_4O_{12}$ BeH_2SiO_4
                             Li_2SiO_3

4 - $BeAl_2Si_4O_{12}$ BeH_2SiO_4
                             Na_2SiO_3

The varieties containing caesium are called: Worobieffite.

The varieties containing no alkalies are called: Aquamarine.

The varieties containing lithium, but no caesium, are called: Lithium beryl.

The varieties containing sodium, but no lithium nor caesium, are called: Sodium beryl.

Clarke[157] considers the normal beryl as having the formula $3 BeO \cdot Al_2O_3 \cdot 6SiO_2$, which he interprets as a metasilicate, although that of a basic trisilicate is given as an alternative. The presence of other elements in small amounts (lithium, caesium, hydrogen, or hydroxyl) is assumed to be due to their replacement of beryllia.

Together with the presence of caesium, etc., the physical properties undergo marked changes, as clearly stated by Ford.[158] He showed that with an increased replacement of beryllium by alkalies (especially caesium) the density, refractive indices, and double refraction all show a marked increase. Together with the presence of caesium, the beryl crystals generally assume a flattened habit, to the

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[156] Vernadsky, W.J., Worobieffite and the chemical composition of beryl: Trav. Musee Geol. Pierre le Grande pres L'Acad. Imp. Sci. St. Petersbourg: vol. 2, pp. 81-102, 1908, (Russian) Abstracted in German, Zeitschr. Kryst. Min., vol. SO, p. 73, 1911.

[157] Clarke, F.W., The constitution of the silicates: U.S. Geol. Bull. 588, p. 1914.

[158] Ford, W. E., The effect of the presence of alkalies in beryl upon its optical properties: Am. Jour. Sci., 4th ser. vol. 30, p. 128, 1910.

height (c-axis) less than the thickness. This is especially well shown in the caesium beryls from Madagascar. This change in habit is, however, not a necessary accompaniment of the presence of caesium. Lacroix and Rengade[159] have studied still further the effect of caesium on the optical properties of beryl. In a reply to a paper[160] containing additional determinations on the same subject Lacroix[161] has shown conclusively that beryl forms a continuous isomorphous series from normal beryl ·without caesium to a caesium-rich beryl and that the physical properties correspondingly vary with the chemical composition.

The fact of this isomorphous relationship being established, it becomes necessary to determine the end members and to see whether the beryl series can be definitely formulated as mixtures of two well- defined end products, each of which could claim to be considered as a definite mineral species.

A study of all the available results published on beryl, and they are considerable, shows that so far there is no warrant for the establishment of two species, one of which would be comparable to Vernadsky's worobieffite. The analyses that show the maximum amount of alkalies present still consist overwhelmingly of the beryllium aluminum silicate.

Localities.

Beryl is one of the minor constituents of pegmatite, but nevertheless is widespread in its distribution. It has been found at nearly all the producing mines at Pala, Rincon, Mesa Grande, and Ramona, and at the various localities in Riverside County.

Occurrence.

The alkali-free beryl has been found in pegmatites that do not show any well-defined middle part but consist throughout of graphic granite or a granular quartz-feldspar rock. The alkali-rich beryls have been found only in the middle part of the ledges, where they occur with the other lithium minerals. An attempt has been made to separate the two occurrences, but in the opinion of the writer the evidence is insufficient.

The associated minerals of the alkali-free beryl (that is, those which are presumably alkali-free) are the common rock-forming minerals of the pegmatite. On the other hand, the associated minerals of the alkali-rich beryls are those of the "pay shoot", containing elbaite, lepidolite, albite, etc. The mode of occurrence of the beryls suggests that they were among the first minerals to form and are contemporaneous or perhaps slightly earlier than the elbaite, lepidolite, and albite. A most remarkable specimen of beryl, described on page 000 and shown in Plate XXXIV F is a repeated intergrowth of beryl and albite, showing that in this case these two minerals were contemporaneous in growth.

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[159] Lacroix, A, and Rengade, The optical properties of rose beryl from Madasgascar: Bull. Societe Francaise Mineralogie, vol. 34, p. 123, 1911.

[160] Duparc, L., Wunder, M., and Sabot, R., The minerals from the pegmatites near Antsirabe in Madagascar: Mem. Soc. Phys. Geneve, vol. 36, fasc. 3, 1910.

[161] Lacroix, A, The continuity of the variation of the physical properties of the beryls from Madagascar in relation to their chemical composition: Bull. Societe Francaise Mineralogie, vol. 35, p. 200, 1912.

Beryl has been found only in crystals in the California field and as found are in isolated crystals, usually well developed (Plate XXXIV A), frequently doubly terminated, or else embedded in the matrix with its associated minerals (Plates XXXII Q). One specimen was obtained from Coahuila that is unique in that it consists of a large number of adhering small crystals about half of which are roughly in parallel position (Plate XXXIV E).

Whereas many of the crystals found are well developed and terminated by plane polished faces with sharp edges (Plate XXXIV C), others are remarkably etched (Plate XXXIV K), and show in their extreme effect, no trace of the original crystal faces (Plate XXXIV J).

In size the beryl crystals show a wide range in the extremes but a vast majority of the crystals do not show much variation. In comparison with the variability of size of the tourmaline crystals, those of beryl are remarkably uniform.

PLATE XXXIV. Beryl crystals.

A. Lone prismatic, bluish-green beryl from the Victor mine, Rincon. Natural size. Presented by Mr. J. Mack. See page 000.

B. Ordinary beryl from Coahuila, Riverside County. Shows an unusual cone-shaped termination, apparently a rounded form of v $\{21\bar{3}1\}$. Enlarged two times. Presented by Mr. K.C. Naylor. See page 000.

C. A short prismatic beryl in clinographic position. Natural size. American Museum of Natural History in New York City. See page 000.

D. An orthographic view of the same crystal.

E. An unusual form of occurrence for beryl. From the Fano mine, Coahuila, Riverside County. Natural size. Presented by Mr. H.C. Gordon. Described on page 000.

F. Basal view of an intergrowth of beryl (light) and albite (dark). Natural size. Pala Chief mine, Pala. Described on page 000.

G. Basal view of tabular pink crystal from Pala Chief mine, Pala. Natural size. The crystal was covered with ammonium chloride. The etchings shown in figure 120 and Plate XXXV are on this crystal. Kindly lent by Col. W.A. Roebling, of Trenton, N. J. Described on page 000.

H. Front view of same crystal.

I. Bottom view of same crystal, showing peculiar step like arrangement absent on the upper surface.

J. A most remarkably corroded piece of transparent colorless beryl from the Himalaya mine, Mesa Grande. Enlarged two times. Note the square etch figures. Kindly lent by Mr. E. Schernikow, of New York City. The specimen was coated with ammonium chloride. Described on page 000.

K. A very remarkable etched colorless beryl from the Surprise mine, Ramona. Enlarged 1 2/3 times. The specimen was coated with ammonium chloride. Kindly lent by Mr. J.D. Farley, of Ramona. A, B, E, F, are in the United States National Museum.

Crystallography.

Previous description.

The difference in habit between the alkali-free beryl (Plate XXXIV) and the alkali-rich beryl (Plate XXXII B) has already been given by Ford.[162] The alkali-free

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[162] Ford, W.E., Beryl crystals from California: Am. Jour. Sci., 4th ser., vol. 22, p.

beryls are long prismatic; whereas, the alkali-rich varieties are short prismatic, nearly equidimensional. Most of these beryls are poor in combinations, and the forms and combinations recorded by Ford are those found on nearly all of the crystals. Ungemach also has described a beryl from Mesa Grande with the forms cm and x.

Forms and angles.

Nearly all of the beryl crystals examined are poor in forms and simple in combination. This is especially true of the alkali-rich pink beryls. The blue and green beryls from Rincon show the forms: m {10$\bar{1}$0}, i {21$\bar{3}$0}, c {0001}, p {10$\bar{1}$1} and s {11$\bar{2}$1}. Large opaque yellow-green beryls from Riverside County show only m {10$\bar{1}$0} and c {0001}. On the small group of pale-blue and green crystals from the Fano mine, near Coahuila, Riverside County, illustrated in Plate XXXIV E several crystals were obtained that showed a much richer combination of forms. Such richly terminated crystals, however, are the exception. The forms observed on these small crystals belonging to the alkali-free variety are shown in the following table, with which are given the calculated values for comparison.

Measured and calculated angles for beryl from the Fano mine, Coahuila, Riverside County, California.

217, 1906.

Letter	Form	Size of face	Reflection	Measured		Calculated	
				φ	ρ	φ	ρ
e	0001	Large	Good	--	0°00'	----	90° 00'
m	10Ī0	Large	Good	0°00'	90°00'	0° 00'	90°00'
a	11Ī0	Small	LineGood	30°00	90°00'	30° 00	90° 00'
ε	5160	face	LineGood	8°36'	90°00'	8° 57'	90° 00'
	10Ī3	face	Poor	0°00'	10°08'	0° 00'	10° 52'
p	10Īl	Small	LineGood Poor	0°00'	29°56'	0° 00'	29° 57'
u	20Ī1	face	LinePoor Poor	0°00'	48°00'	0° 00'	49° 03'
t	4041	face	LinePoor	0°00'	66°30'	0° 00'	66° 32'
	11Ī6	face	Line	30°00	21°52'	30° 00'	22° 01'
o (a)	11Ī3	face	Poor Poor	30°00	18°17'	30° 00'	18° 24'
			Poor Poorl				
	2245	Line	facePoor Poor	30°00'	33°24'	30° 00'	33° 38'
	4487	Line	facePoor Poor	30°00'	40°17'	30° 00'	40° 16'
s	11Ī1	Line	face	30°00'	44°57'	30° 00'	44° 56'
	5494	Line	facePoor	26° 26'	47°32'	26° 20'	48° 22'
	5272	Line	face	15°34'	61°46'	15° 30'	61° 30'
n	3141	Line	facePoor	14° 33'	60°19'	13° 54'	64° 18'
v	5161	Line	face	8°34'	73°11'	8° 57'	72° 41'
	6171	Line face		7°08'	75°43'	6° 54'	75° 40'
β	11.1. Ī2.1						
	12.1. Ī3 .1	Line face		4°41'	81°03'	4° 18'	81° 26'
h	19.1.0Ī0 .1						
	20.1.Ī1.1	Line face		2°23'	85°40'	2° 32'	84° 55'

a This form is listed as {11Ī3} in Dana's "The System of Mineralogy, Descriptive Mineralogy, p. 405, 1914.

The forms on the large alkali-rich crystals were measured with the contact goniometer and were easily determined as they lay in well-defined zones. The measurements need not be repeated. The forms observed are c{0001}, m {10Ī0}, p {10Ī1}, s {11Ī1}, and v {21Ī1}: Ungemach[163]159 has described two pink beryls from Mesa Grande showing the combinations: (1) c {0001}, m {10Ī0}, s {11Ī1}, {1.1. Ī.20}, and the vicinal form {1.0.Ī.35}.

Combinations.

The combinations observed on the long prismatic crystals, which presumably are all alkali free, are as follows:

Combinations observed on alkali-free beryls.

[163] Ungemacb, H., Notes mineralogiques. T. Beryl: Annales Soc. Geol. Belgique, Mem. 39, p. M427, 1912.

Color	Locality	Describer	Habit	Size	Combination
Yellowish green	Coahuila	Schaller	Prismatic	Large, abundant	cm
Bluish green	Coahuila	Schaller	Prismatic	Large, abundant	cm
Green	Rincon	Ford	Prismatic	60 by 4 mm	c m l p s
Green	Rincon	Schaller	Prismatic	27 by 7 mm	c m s
Blue	Rincon	Schaller	Prismatic	Large	cm
Blue	Rincon	Schaller	Prismatic	44 by 5 mm	c m l s
Blue	Rincon	Schaller	Prismatic	45 by 6 mm	c m l p

The combinations observed on the short crystals, generally pink and presumably all alkali rich, are shown in the following table:

Combinations observed on alkali-rich beryls.

--- indicates data not measured or not provided by the author. Equidi, equidimensional

Color	Locality	Describer	Habit	Size	Combination
Pink	Mesa Grande	Ford	Tabular		cms
Pink	Pala	Ford	Tabular		cmpsv
Pink	Pala	Ford	Tabular		cmps
Pink	Mesa Grande	Ungemach	-----	------	cms {1.1.2.20} {1.0.T.35}
Pink	Pala	Schaller	Equidi	------	cmapsv
Pink	Pala	Schaller	Equidi		cmpsv
Pink	Pala	Schaller	Equidi	55 by 30 by 18 mm	cmpsv
Colorless	Pala	Schaller	Equidi	25 by 25 by 15 mm	cmpsv
Pink	Ramona	Schaller	Short prismatic	37 by 27 by 25 mm	cmps
Colorless	Ramona	Schaller	Short prismatic	26 by 23 by 16 mm	cmps
Pink	Oak Grove	Schaller	Equidi.	36 by 38 by 38 mm	cms
Pink	Coahuila	Schaller			
Pink	Oak Grove	Schaller			cm
Pink	Pala	Schaller	Equidi.	Small	cmpsv
Pink	Pala	Schaller	Equidi.	Small	cmps
Pink-	Pala	Schaller -	Eauidi.	Small	cmpso

Habit

Description of crystals.

The alkali-free crystals invariably have a long prismatic habit as shown in Plate XXXIV. The crystal from Rincon described by Ford as having almost ideal symmetry is reproduced in figure 112.

FIGURE 112. Akali-free_prismatic green crystal from the Mack mine, Rincon.

After Ford. Forms: m {10$\bar{1}$0}, i {21$\bar{3}$0}, c {0001}, p {10$\bar{1}$1}, s {11$\bar{2}$1}.

A somewhat similar crystal from the same locality, but stouter and not so long, showed bright line faces of the form {11$\bar{2}$2} truncating the edges pp'. Other crystals from this locality showed only m {10$\bar{1}$0} and c {0001}. The crystals from the Fano mine, at Coahuila, with the rich combination of forms, are similarly long prismatic with essentially m {10$\bar{1}$0} and c {0001}, the other forms being very minute.

The pink alkali-rich beryls, on the other hand, are nearly all wider than high, that is, their habit is nearly equidimensional to tabular. This difference in habit of the two varieties has been clearly described by Ford. 160 A crystal from Mesa Grande, figured by Ford, is short prismatic in habit, being one of the few cases observed on these pink beryls where the c-axis is longer than the horizontal axis. Ford's drawing is reproduced in figure 113.

FIGURE 113.-Pink beryl from Mesa Grande, with a short prismatic habit. After Ford. Forms: m {10$\bar{1}$0}, c {0001}, p {10$\bar{1}$1}, s{11$\bar{2}$1}.

A pink crystal from Oak Grove is equidimensional and simple in combination with only c m s and is shown in figure 114.

FIGURE 114.-Pink beryl from Oak Grove. Forms: m {10$\bar{1}$0}, c {0001}, s {11$\bar{2}$1}.

FIGURE 115.-Tabular pink beryl with large base from Pala. Forms: m {10$\bar{1}$0}, c {0001}, p {10$\bar{1}$1}, s {11$\bar{2}$1}.

FIGURE 116.-Tabular pink beryl with small base, Pala. Forms: m {10$\bar{1}$0}, c {0001}, o {10$\bar{1}$1}, s {11$\bar{2}$1}, v {21$\bar{3}$1}.

FIGURE 117.-Pink beryl from Pala with large development of s {11$\bar{2}$1}. Forms: m {10$\bar{1}$0}, c {0001},p {10$\bar{1}$1}, s {11$\bar{2}$1}, v {21$\bar{3}$1}

FIGURE 118.-Pink beryl from Mesa Grande, tabular habit, after Ford. Forms: m {10$\bar{1}$0}, c {0001}, s {11$\bar{2}$1}.

160 Ford, W.E., Some interesting beryl crystals and their associations. Am. Jour. Sci., 4th ser., vol. 22, p. 217, 1906.

FIGURE 119. Pink beryl from Pala showing trigonal shaped base. Forms: m {10$\bar{1}$0}, c (0001), p {10$\bar{1}$0}, s (11$\bar{2}$1), and o {11$\bar{2}$2}.

A tabular crystal from the Pala Chief mine, Pala, showing a large base with the simple combination c m p s is shown in figure 115 and also in Plate XXXIV G. A tabular crystal from the same mine but with a small base is shown in figure 116. With the suppression of the base, the other form notably s {11$\bar{2}$1}, become large, and figure 117 shows a crystal whereon the faces of s {11$\bar{2}$1} are larger than those of any other form.

A tabular crystal from Mesa Grande, figured by Ford, is reproduced in figure 118, for the interesting habit it shows on one crystal a decidedly trigonal development of the base was noted as shown in figure 119.

In this connection it is interesting to note that Lacroix [164] has described an alkali-rich beryl from Madagascar that shows triangular flutings produced by corrosion on the face of c {0001}. Possibly, as suggested by Lacroix, a trigonal symmetry characterizes these alkali beryls. See further under "Etching" on page 000, for apparent differences between the symmetry of the alkali-free and the alkali-rich beryls.

Etch figures.

Some of the crystals that preserve their shape are remarkably covered with etch figures; whereas, others have been partly dissolved by the etching process. The blue-green crystals from Rincon have been attacked by solutions yielding etched terminations, which in their present state show no oriented relation to the crystal symmetry. The ends have become tapered off more or less to a point. These etched beryls are associated with the attacked crystals of perthite (illustrated in Plate XXIV F) and Waring[165] in describing these says:

"… the surface of the orthoclase perthlte crystals Is often corroded Into a series of sharp ridges by the removal of mlcroclIne and greater resistance of the albite to alkaline waters, as shown In the twin crystal illustrated. [His illustration is similar to the one shown In Plate XXIVI F] Iron oxide also seems to be deposited by these waters, in the Interstices of the crystals, staining them red." Many of the beryls are also corroded or partly dissolved, as shown in Plate XXVI, fig. 2. "... The alteration of microcline and albite to kaolinite and muscovite with the liberation of silica and the alkaline carbonates seems to take place to considerable extent, and is thought to be the origin of the clay In the pockets." Here (at Rincon) corroded crystals of orthoclase and corroded beryls occur together in a matrix of sticky red clay composed for the most part of Iron-stalned mica and kaolin. It seems clear that the microcline has first yielded to the meteoric waters and been reduced to kaolin and mica. The waters, made more alkaline by the liberated potash, have then attacked the beryls and partly dissolved them. Muscovite often occurs as fine flakes on the larger beryls, seemingly as a product of alteration.

I am more inclined to the belief, however, that such attacks and solutions as these beryls have suffered are due more to secondary magmatic alterations than to secondary weathering processes, which, it would seem, Waring had in mind in speaking of waters that derived their alkalinity from decomposing feldspar. The production of well-defined etch figures seems to be much more a result of secondary weathering processes than the solution effects observed on these beryls. The relation of these two kinds of etching or solution has been discussed under spodumene. The production of muscovite, apparently derived from the beryl, also would indicate magmatic alteration comparable to that undergone by the schorlite or black tourmaline from this same locality. A greenish-yellow beryl from Coahuila (near Hemet), kindly presented by Mr. K. C. Naylor, showed the unusual cone-shaped termination illustrated in Plate XXXIV B. The angle of the etched surface to the prism m is about 33°; therefore, c {0001} to the etched surface is 57°, which agrees with the value for the form v {$21\bar{3}1$}, for which $c \wedge v = 56° 44'$.

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[164] Lacroix, A, The minerals of the pegmatite veins with lithium tourmalines from Madagascar: Soc. Francaise Mineralogic bull. vol. 31, p. 238, 1908.

[165] Waring. G.A, The pegmatite veins of Pala, San Diego County: Am. Geo., vol. 35, pp. 365, 369, 1905.

A number of the blue-green crystals from Ramona, similar in color and habit to those described by Waring as "corroded beryls and exhibiting action of meteoric waters" show well-developed etch figures on the unit prism faces. One such crystal are shown in Plate XXXIV K and a photomicrograph of part of another crystal having the rectangular etch figures, is shown in Plate XXXV A and B. The outline of these etch figures to show their symmetry is given in figure 120 A and B. For comparison the etch figures   observed on a prism face of a tabular pink crystal from Pala, are reproduced in Plate XXXIV G and are shown diagrammatically in figure 120 C.

FIGURE 120.-Etch figures on prism m of beryl, showing symmetry. A and B, blue-green, alkali-free, prismatic crystals from Rincon; C, pink, alkali-rich, tabular crystal from Pala.

What the relation is between the different symmetry of the etch figures on the two kinds of beryl to the chemical composition is not known, but it is very suggestive especially in consideration of the facts stated earlier on page 000. On the other hand, the etchings on the other faces of the pink crystal showing the six-sided figures on the prism faces are entirely in accord with the requirements of the holohedral symmetry possessed by the blue-green crystals.

The etchings on the basal pinacoid c {0001} are hexagonal in symmetry, the sides of the hexagon being parallel to the edges between c {0001} and s {11$\bar{2}$1} and normal to the edges c {0001} and m {10$\bar{1}$0}. Many of them are very symmetrical; other are distorted. At places rows of similarly distorted figures parallel to the edges c {0001} and m {10$\bar{1}$0} are in parallel position. Some of the figures are equally spaced from each other; however, again, they overlap and are irregular in their distribution.

Twelve-sided figures were also observed and by incomplete development of the sides, also 7, 8, 9, 10, and 11 sided figures are shown in the sketch of figure 121.

FIGURE 121.-Etch figures on basal pinacoid c {0001} of pink, alkali-rich, tabular crystal from Pala.

The etch figures on p {10$\bar{1}$1} are hexagonal in shape, two of the sides being parallel to the edge c {0001} and p {10$\bar{1}$1}. The etch figures on s {11$\bar{2}$1} are well-developed, triangular in shape, and shown in Plate XXXV F.

PLATE XXXV. Etchings on beryl. [All natural etchings.]
A. Rectangular etch figures on prism m {10$\bar{1}$0} on bluish alkali-free, prismatic crystal from Victor mine, Rincon. Natural size. Described on page 000.
B.   Similar rectangular etch figures on a similar crystal as described in A. Enlarged two times. See page 000. Specimens A and B in the collection of Col. W. A. Roebling, of Trenton, N.J.
C.   Elongated rectangular etch figures on m{10$\bar{1}$0} of bluish, alkali-free, prismatic crystal from the Victor mine, Rincon. Enlarged 20 times. Described on page 000.
D. Beryl with etchings, Surprise mine, Ramona. Kindly lent by Mr. J.D. Farley, of Ramona. Enlarged 1 2/3 times. See page 000.
E. Hexagonal etch figures on prism m{10$\bar{1}$0} of pink, alkali-rich, tabular crystal from Pala.
F. Triangular etch figures on pyramid s {11$\bar{2}$1} of same crystal of E.
G. and H.   Hexagonal etch figures on base c {0001} of same crystal as E. The beryl crystal having the natural etchings shown in E, F, G, and His illustrated in Plate

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XXXIV. It belongs in Col. W.A. Roebling, of Trenton, N. J.

The symmetry of the etch figures observed on the different forms of this pink tabular crystal are grouped together in figure 122 and, as can readily be seen, indicate holohedral hexagonal symmetry.

FIGURE 122. etch figures on pink tabular crystal from Pala showing symmetry of crystal. Forms: m {101bar0}, c {0001}, p {101bar1}, and {112bar1}.

A series of remarkable etchings are developed on two colorless transparent beryl crystals from Ramona, which were photographed after being coated slightly with a layer of ammonium chloride and are reproduced in Plate XXXV D. Drawings of the same etchings are shown in figure 123. These etchings are probably similar to those described by Ford[166] on two perfectly transparent and yellow-colored beryl crystals from Ramona. Ford describes the etchings as follows:

"These are in the form of depressions arranged singly in line (fig.9) or in groups (fig. 10), in the positions which would naturally be occupied by faces of the prism m. The prism m, however, does not appear on the crystals, the groups of pits corresponding in position to adjacent m faces being separated from each other by a dihexagonal prism. Measurements of a series of the faces forming the pits were made on a two-circle goniometer and the average of the results obtained were used to plot the positions of the faces on a gnomonic projection (fig. 8), the plane of projection being taken as parallel tom{10-10}. From this projection figures 9 and 10 were made, which show the character and arrangement of the etched pits drawn in orthographic projection upon a plane parallel to m. The faces were all rounded and gave only approximate measurements, consequently no definite symbols can be assigned to them. The dihexagonal prism designated as I which appears on the crystals and forms prominent faces in the pits, is close to a form having {31-40} as its symbol. The faces in the pits marked I are the same as the right hand prism face {31-40}, also marked I, and reflect the light simultaneously with it; and those marked r reflect together with the left hand prism face, {41$\bar{3}$0},designated as r. The bottoms of the pits are usually occupied by two small faces making a very acute angle with one another which correspond to the two prism faces designated as r and r' (fig. 9), which lie to the right and left beyond those marked I and r. Figure 11, which is a horizontal section along the dotted line in figure 9, illustrates the relations existing between the faces of the dihexagonal prism and the corresponding faces found in the pits. The pyramid of the first order, designated as 2, which always forms the upper and lower faces of the pits, approximates in its position to {13.0.1ba$\bar{3}$2}. In addition to these faces the etchings show two other forms, 3 and 4, which in their positions correspond to the faces of dihexagonal pyramids. They are of vicinal character, falling very close to the prism face m, as is shown in the gnomonic projection, one averaging only 4° 57' and the other 2° 13' from m. Because of the uncertainty of the measurements due to the vicinal character of the faces, exact symbols cannot be assigned to these forms. In some places the pits form a single line down the length of the crystal, not encroaching at all on the faces of the dihexagonal prism at the sides, as shown in figure 9. More generally they are in two or more parallel and adjacent lines and interlock with each other in a very complicated manner, as shown in figure 10. The pits average 2 mm by 1.5 mm in size. The crystals show a tendency to taper at the ends on account of the

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[166] Ford, W.E., Some interesting beryl crystals and their associations: Am. Jour. Sci., 4th ser., vol. 22, p. 221, 1906.

etching and rounding of the prism faces."

FIGURE.123.-Etching on beryl from Ramona, after Ford. A, gnomonic projection of etch faces, m {10-10} being taken as plane of projection; B, single line of etching; C, group of etchings; D, horizontal section along the dotted line of B. I= {31-40}, r {41$\bar{3}$0}; r and r' two other prism faces, 2 {13.0.1bar$\bar{3}$.2} approximately; 3 and 4 vicinal dihexagonal pyramids near to m {101bar0} in position.

Inclusions.

A small prismatic colorless crystal in the American Museum of Natural History (Spec. No. 10347) in New York City, shows a remarkable set of inclusions. The transparent crystal, 42 mm long and between 6 and 7 mm wide contains 20 plates or layers of inclusions, most of them equally spaced. These layers of inclusions, their position in the crystal being shown in figure 124, are parallel to the base and consist of numerous inclusions of bubbles, which appear black and are probably gaseous. The appearance of one of these layers, viewed obliquely, is shown in figure 125. The crystal not being available for further study, the composition and properties of these inclusions could not be determined.

FIGURE 124.-Beryl crystal showing position of 20 layers of inclusions.

FIGURE 125.-Sketch of layer of inclusions in beryl, viewed obliquely.

Physical Properties.

Density.

The increase of the density of beryl due to the presence of alkalies, especially caesium, has been strikingly shown by Lacroix [167] in a compilation of the densities of beryl from Madagascar, the values ranging from 2.7027 to 2.910. Ford[168] has determined the density of two California beryls, both pink and containing alkalies, as 2.714 (Mesa Grande) and 2.785 (Pala).

Optical Properties.

Color.

The alkali-free beryls from Rincon are blue or green in various shades and combinations and the common beryls (c m) found in several of the pegmatites in which no lithium-bearing-bearing minerals had been found, are mostly of a yellowish-green. The alkali-rich beryls are nearly all pink or rose. A few are colorless, yellowish, or brownish, perhaps resulting in part from the fading of an original pink or rose.

Refractive indices.

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[167] Lacroix, A, Sur la continuite de la variation des proprietes physignes des beryls de Madagascar, en relation anec leur composition chimique: Bull. Soc. Franc. Mineralogic, vol. 35, p. 200, 1912.
[168] Ford, W.E., The effect of the presence of alkalies in beryl upon its optical properties: Am. Jour. Sci., 4th ser. vol. 30, p. 128, 1910.

The refractive indices increase with the amount of alkalies present and the birefringence also becomes stronger.

Quantitative composition.

A single analysis was made of one of the large pink beryls from Oak Grove with the results shown below, to which are added the analyses of Ford on material from Mesa Grande and from Pala. It is greatly regretted that time was not available to continue the chemical investigation of these interesting beryls from California.

Analyses of pink beryls from California.
---- indicates that data provided]

Locality-	Oak Grove	Mesa Grande	Pala
Analyst Constituents	Schaller	Ford	Ford
SiO_2	62.95	64.98	-----
Al_2O_3	17.79 a	17.86	-----
BeO	11.40 a	13.42	-----
K_2O	0.99	0.46	1.33
Na_2O	2.53	0.84	1.59
K_2O	0.00	0.18	0.28
Ca_2O	1.60	0.00	0.57
H_2O	2.49	2.16	-----
Total	99.75	99.90	------
Density	2.753	2.714	2.785

a During the course of the analysts by the writer a slight amount of the solution containing Al_2O_3 and BeO was lost. The percentages of these oxides as actually determined are, Al_2O_3 17.02 percent; and BeO, 10.91. Since the ratio of SiO_2 to Al_2O_3 is 6:1, the percentage of Al_2O_3 has been raised from 17.02 to the value required (17.79) to give exactly the ratio of 6:1. The value for BeO was then correspondingly raised from 10.91 percent to 11.40 percent

Topaz.

Occurrence.

Topaz has been found (positively) only at Ramona, although numerous other localities have been reported as yielding the mineral. Examination of the specimens from the other localities has invariably shown the supposed topaz to be quartz, generally in distorted crystals. At Ramona it has been found, so far as is known, only at the Little Three mine (Plate XXVIII G) and at the Surprise mine (Plate XXVIII F).

At the Surprise mine topaz was found as loose crystals in the pockets near the center of the ledge. These pockets are well shown in Plate XXIII B. The topazes from this mine are all etched and only a few crystals were seen that still retained any plane

and polished terminal faces. Those of the prism zone, however, still retained their evenness and high polish. No matrix specimens from this mine were seen, so that the direct associations of the topaz are not known. Several of the crystals showed terminations at both ends.

The topazes from the Little Three mine were much more abundant, and numerous specimens with the associated minerals were collected. At this mine the topazes were found as isolated crystals slightly imbedded in and firmly adhering to green tourmaline (Plate XXVIII G), albite, and orthoclase (Plate XXVII C). They also formed, with green tourmaline, albite, and lepidolite, a cavernous conglomeration similar in appearance to the specimen shown in Plate VIII C, into whose cavities projected well-defined crystals of the same minerals. In a third mode of occurrence the topaz is distinctly later than the green tourmaline, albite, and lepidolite, for these latter three minerals form radiating groups over which are irregularly sprinkled isolated, well-formed topaz crystals, very distinctly of a later period of formation than the three minerals on which they rest. The formation of topaz continued after the green tourmalines, albite, and lepidolite had ceased their growth, so that instead of two distinct generations of topaz, there was only one which had a long formation period.

Some of the specimens from the Little Three mine were very beautiful, the bluish-clear crystals being perched on albite and greatly resembling the Russian specimens. The largest crystal from this locality is in the British Museum and Dr. L. J. Spencer has very kindly furnished its dimensions. The isolated crystal of a pale-blue measures about 7.5 cm in thickness in the three directions of the crystal axes. Its weight is 676 grams. A second large crystal, shown in Plate XXVIII F and now in the United States National Museum (No. 86,218) measures 5.8 cm in height and 3.3 cm in thickness. The colorless to pale blue, partly transparent crystal weighs 91 grams.

Crystallography.

Forms and angles.

The topaz crystals from the Surprise mine showed the forms: c {001}, b {010}, m {110}, M {230}, l {120}, g {130}, β {011}, f {021}, y {041}, i {223}, n {111}, o {221}, d {201}, x {243}. The average of the measured angles compared well with the calculated values.

The crystals from the Little Three mine are much better developed and not rounded by etching, so that the faces could be accurately measured and the forms determined. Nearly all of these crystals are completely developed with holohedral symmetry. The forms noted are c {001}, b {010}, m {110}, M {230}, l {120}, g {130}, β {011}, f {021}, y {041}, i {223}, u {111}, o {221}, d {201}, x {243}.

Habit.

The habit of the crystals from the Surprise mine is shown in figure 126. The common habit of the crystals from the Little Three mine is different, the crystals having a decided wedge shape, due to the large development of the dome y {011}. The habit of many of the crystals is shown in figure 127. A second extreme habit, produced by a larger development of the base and crystal of this habit, is shown in figure 128. All gradations between these two habits are to be found.

FIGURE 126.-Topaz crystal, Surprise mine.

FIGURE 127.-Wedge-shaped topaz crystal, Little Three mine.

FIGURE 128.-Rarer habit of topaz crystal, Little Three mine.

Etchings.

The crystals from the Surprise mine are very much etched, especially on the terminal faces. No opportunity was had of studying these etchings in detail, but a general view of the character of the etch figures on the different faces is shown in figure 129.

FIGURE 129.-Etch figures on topaz crystal, Surprise mine.

Muscovite.

Occurrence.

Muscovite is one of the essential minerals of the pegmatite and is found at every place where pegmatite occurs. Its relative amount varies greatly but the mineral has been identified in every pegmatitic exposure seen. The appearance of the muscovite in the fine-grained lower rock of the second group pegmatites has already been given on page 000. In the hand specimen the irregularly bounded plates have a greenish-white color, which is stronger in the larger plates of the coarsely granular rock of the first-group pegmatites. The lower portion of the graphic section of the ledge, just above the middle part, contains large plates of muscovite, which often show a well-developed crystal outline. The wedge-shaped books are also abundant here. The best development of muscovite is in the middle part of the ledge, particularly in the pay shoot.

The occurrences in the pay shoot alone being considered, the association of orthoclase, quartz, and muscovite is characteristically abundant, as is the muscovite-free association of albite, quartz, lepidolite, and tourmaline. Wherever tourmaline is found with muscovite, the tourmaline is always of a green color; whereas, if associated with lepidolite the tourmaline is mostly reddish hue. Orthoclase is much more abundant than is albite with muscovite, and the two following associations are very characteristic: (1) green tourmaline+ orthoclase+ muscovite+ quartz, and (2) red tourmaline+ albite+ lepidolite+ quartz. Inasmuch as it has been shown for tourmaline that the usual order of formation is black → green → red, it follows that the association (green tourmaline, muscovite, orthoclase) was formed before the association (red tourmaline, lepidolite, albite). Muscovite is, therefore, older than lepidolite, which agrees with the fact that the intergrowths of these two minerals are nearly always with lepidolite around muscovite. A few cases were noted where a second generation of muscovite surrounds the lepidolite border, but this in turn always surrounds the earlier first-generation muscovite.

Inclusions of garnet and green tourmaline in muscovite are not rare, and it seems as if these minerals had crystallized earlier than the mica. With quartz and feldspar, muscovite was nearly contemporaneous, though the specimens of short prismatic crystals from Ramona (Plate XXXVII C) indicate that these muscovite crystals were formed later than the feldspar.

The order of succession, expressed in very general terms is tourmaline and garnet, microcline, albite, muscovite, lepidolite, although the overlapping of time of

formation was in some cases very great.

Plates bounded by crystal outlines are abundantly developed in the middle part and in the lower portion of the graphic granite, just above the middle part. They commonly have a wedge-shape as shown in figure 133, and on the basal cleavage show the feather striation due to the development of parallel lines from the traces of the gliding planes. (See figures 130 and 131) Many of these muscovite plates are surrounded by a rim of lepidolite as shown in Plate XXXVII A and D. These successive growths of the two micas are especially well developed at the Tourmaline Queen mine, at Pala, and at the San Diego mine, at Mesa Grande, though they have also been found at nearly all of the localities.

Fine-grained scaly masses are not very abundant, although they occur in all the pegmatites. When these masses become coarser-grained they pass into large irregular flakes and imperfect crystals, and become more a component of the rock than a sample of a mineral. A specimen from Pala Chief Hill exfoliated considerably when heated in the blowpipe flame but was not investigated further.

A compact, very fine-grained variety was noted in abundance at the Esmeralda mine, at Mesa Grande. Microscopic examination showed an aggregate of minute muscovite scales interspersed with a little quartz and feldspar. On some of these specimens are minute black metallic crystals, probably some variety of columbite.

A loose, powdery form of the compact variety was also encountered at the Esmeralda mine. It is identical with the form described, except in its mode of occurrence as a loose powder.

Tabular hexagonal crystals of muscovite are not common but have been observed at several of the mines, notably at Pala. Rogers[169] has described large tabular hexagonal crystals from the Mack mine at Rincon, with the forms: c {001}, b {010}, M {110}.

Short prismatic crystals were abundantly found at Ramona where they partly cover black tourmaline, albite, and orthoclase crystals (Plate XXXVII J). The crystals are rounded prisms, striated vertically, and are from 0.5 to 1 cm long (c axis) and from 0.33 to 0.5 cm thick. Cleavage pieces, examined under the microscope, show that these crystals are repeatedly twinned similar to the large lepidolite plates, without defined crystal outline illustrated in Plate XXXVI C.

Short prismatic crystals were also observed on a specimen from the Pala Chief mine, at Pala. The large crystals reach a length of nearly 4 cm with a thickness of 2 by 1 cm. They are associated with larger quartz crystals, albite, and considerable cookeite and clay in which are embedded fragments of black tourmaline. Minute greenish-black tourmalines(?) are also partly embedded in the surfaces of the quartz. The albite appears in places to have been corroded. The most interesting fact about the specimen, illustrated in Plate XXXVI A, is that these muscovite prisms have been changed to lepidolite, as described on page 000.

Long prismatic muscovite crystals grouped in parallel position were noted on several specimens from the Anita mine, in Riverside County. The long slender crystals, pink in color, surround a lepidolite border and constitute an occurrence of the second-generation muscovite mentioned. The individual crystals are poorly developed, but they resemble the similar pink fibrous muscovite described by

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[169] Rogers, A.F., Minerals from the pegmatite veins of Rincon, San Diego County, California: School of Mines Quart., vol. 31, p. 214, 1910

Bowman[170] on lepidolite from Connecticut.

Physical properties.

Cohesion.

Muscovite responds very well to pressure resulting in the production of the so-called pressure figures. The traces of the gliding planes produced, as seen on the basal cleavage, yield three series of parallel lines as shown in figure 130.

FIGURE 131.-Muscovite breaking along pressure lines.

This effect is very commonly observed in muscovite from pegmatites. It is very well developed on the muscovite embedded in the massive quartz in the San Diego mine, at Mesa Grande. These muscovite plates easily break along these pressure lines and form rectangular sheets as shown in figure 131. The pressure lines extend without a break into the surrounding lepidolite border. On the thicker pieces well developed gliding planes are seen, with highly polished but uneven surfaces corresponding to figure 135.

Optical properties.

Most of the muscovite has the ordinary color. Specimens are nearly colorless, pale green, yellow, or gray, and, more rarely, pink. Pink-colored crystals are especially developed for the muscovite from the Tourmaline Queen and the San Diego mines, these specimens usually have a border of purple lepidolite, although some show pink and yet are free from any lepidolite border. The pink color rarely permeates the muscovite; much more commonly it is developed in the portion adjacent to the lepidolite border.

[EUGENE FOORD--Add refractive indices for muscovite as Schaller intended perms p. 798 and 799. page 799 is actually missing--probably was the missing table – comment by Tom Kohnen at the USGS]]

Chemical properties.

Quantitative composition.

The unusual pink color of some of the muscovite from the San Diego mine, at Mesa Grande, made it desirable to see if the mineral possessed any unusual composition, and a carefully selected sample, free from any adhering lepidolite, was prepared and analyzed, with the following results:

Analysis and ratio of pink muscovite, San Diego mine, Mesa Grande.
[W.T. Schaller, analyst]

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[170] Bowman, H. L., On an occurrence of minerals at Haddam Neck, Connecticut, U.S.A.: Mineral. Mag., vol. 13, p. 98, 1902.

Constituent	Analysis	Molecular ratios	
SiO2	45.63	0.7567	12.00
Al2O3	37.42	0.3661	5.81
Mn2O	0.06	0.0004	---
Li2O	0.20	0.0067	0.11
Na2O	1.43	0.0231	2.05
K2O	9.95	0.1056	
H2O	4.43	0.2461	
F	0.77	0.0405	4.22
Subtotal	99.89		
Excess O	0.32		
Total-	99.57		

The analysis is that of a typical muscovite, approximating closely in its ratios to the muscovite formula $12SiO_2 \cdot 6Al_2O_3 \cdot 2K_2O \cdot 4H_2O$. A very small amount of the lepidolite compound (see p. 000) seems to have entered into combination with the muscovite, furnishing the $Li_2O \cdot Mn_2O$ and F. So, too, the ratio of Al_2O_3 indicates a slight admixture of the lepidolite compound poor in alumina, whereby the ratio of Al_2O_3 is reduced from 6.00 to 5.81. But the amount of the lithium-bearing silicate is very small, and the mineral is a normal muscovite.

Alteration.

Muscovite is a very stable mineral, and a well-established case of its alteration to another definite mineral is, therefore, of considerable interest. One specimen (Plate XXXVI A) from the Pala Chief mine, at Pala, shows several large crystals of mica associated with quartz and albite crystals. One of these crystals consists of a core of muscovite surrounded by a lepidolite border. All the other crystals have been completely altered to lepidolite. The alteration must necessarily have been magmatic, as the elements added to the muscovite--namely, fluorine and lithium--are magmatic elements and not those of secondary weathering processes. The border of lepidolite around the muscovite core (shown enlarged in Plate. XXXVI B) is of similar character to the lepidolite of the other crystals. The lepidolite consists of an aggregate of parallel oriented minute rhombs of lepidolite, (some of them in twinned position) shown both as enlarged and as a microphotograph in Plate XXXVI D. The termination of the mica crystals is covered with cookeite and clay, through which the lepidolite prisms protrude. On exposing a new surface by cleavage, the mica crystals are seen to be built up solidly of these lepidolite rhombs.

The contact of muscovite and lepidolite shown in Plate XXXVI E is shown also diagrammatically in figure 132 and as a photomicrograph in Plate XXXVI F.

FIGURE 132.-Diagrammatic sketch of contact between muscovite core and lepidolite border. Specimen (illustrated in Pl. XXXVI E) from the Pala Chief mine, Pala.

PLATE XXXVI. Alteration of muscovite to lepidolite.
A. Specimen with altered crystals of muscovite.
B. Muscovite core with lepidolite border.
C. Structure of altered mica crystal.
D. Microphotograph of secondary lepidolite.

E. Microphotograph of contact of two micas.
F. Microphotograph of lepidolite.

Lepidolite.

Nomenclature.

The term lepidolite has generally been recognized as referring to a single and well-defined mineral species. But it has been known for some time that there are several varieties of lepidolite readily distinguishable by their optical properties. The term "macrodiagonal" has been used where the axial plane is parallel to the macropinacoid. a {100}, or normal to the brachypinacoid. b {010}; the term "brachydiagonal", where the axial plane is parallel to the brachypinacoid. b {010}. The terms "of the first class" and "of the second class" have been used in a synonymous sense.[171] Baumhauer[172] has proposed the terms macrolepidolite and microlepidolite for those varieties in which the axial angle is large and small, respectively. In a recent paper the same author[173] describes a variety in which the axial angle is nearly zero; whereas, in most cases the axial angle is large.

Chemically, the essential components of lepidolite are silica, alumina, potassia, lithia, and fluorine. The alumina is replaced to a small extent by iron and manganese, and the fluorine is partly replaced by hydroxyl. Soda is also present in small amounts. The elements first named are present in overwhelming amounts in all the recorded analyses, so that no distinct formula, due to the indicated replacements, can be considered as established. There is, nevertheless, a considerable variation in the analyses, and the composition of the samples analyzed from the different localities can not be expressed by a single formula. The direction of the variation and the character of the isomorphous replacement can be determined, but quantitatively they can not yet be definitely formulated. Such minerals as irvingite and polylithionite indicate the type of compounds that in combination help to form the lepidolite series. Only a single analysis of irvingite has been published, and the several polylithionite analyses, though agreeing in general terms, show too much variation and are not sufficiently determined analytically to allow of a definite and conclusive formulation of their composition.

For the present then, it must suffice to consider lepidolite as a specific name in a broad sense, including the mixture of several compounds not yet definitely known. The absence of ferrous iron distinguishes lepidolite from zinnwaldite and cryophyllite and the absence of the silica percentage from irvingite and polylithionite.

Localities.

Lepidolite is one of the most widespread and abundant minerals of the middle part of the pegmatites and has been found at all of the localities exploited where any lithium-bearing minerals were obtained, except at the Hamilton mine in Riverside County.

At Pala, it is very abundant in fine- to medium-grained granular masses in the

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[171] Scharizer, R., Twinning structure of lepidolite: Zeit. Kryst. Min., vol. 12, p. 6, 1886.

[172] Eclogae geol. Helvetize, vol. 7, p. 354, 1903.

[173] Baumhauer, H., The crystal structure of lithium micas and the intergrowth of lepidolite and muscovite. Zeit. Kryst. Min., vol. 51, p. 344, 1912.

Stewart mine; in scaly masses and large plates in the Tourmaline Queen and Tourmaline King mines; in the Pala Chief mine in various forms, generally, in imperfect crystals, but also in granular masses; in various forms on Hiriart Hill, as scaly granular masses at the Katerina, as hexagonal crystals at the San Pedro, and as intergrowths in the Hiriart--but all these forms can be found in nearly every mine, though the forms enumerated maybe more characteristic for any particular mine. At several other prospects around Pala, lepidolite has been encountered, usually in small amounts. It has been found near Bonsall, at Rincon, and at several claims near Oak Grove. In Riverside County … [digital printout ends … check original text]

Order of succession

The available specimens form the criterion for a determination of the order of succession, and it may well be that other specimens might disprove some of the suggestions made herein. Any statement as to the probable order of formation is necessarily only an approximation to the truth and additional specimens and information will always cause changes. The statements made, therefore, are by no means to be considered as final but only as a working hypothesis.

The following minerals seem to have, in part at least, formed before lepidolite: fluorite, apatite, the columbite group, microlite, hatchettolite, montebrasite, triplite, lithiophilite, garnet, spodumene, and beryl; those contemporaneous in formation \\ith lepidolite are microcline, albite, pink and green tourmaline, and muscovite; and those formed after the formation of lepidolite are bismuth ochers, iron and manganese oxides, cookeite, stilbite and other zeolites, and the various clays.

The period of formation of lepidolite was a long one, and there were stages in it when the series of minerals formed was different from that of another stage, yet all this time lepidolite itself was forming. In correlation with these different stages are the different forms of lepidolite--the well-formed crystals, the large plates, the fine-grained granular aggregates. Then, too, the intergrowths of lepidolite with muscovite, especially the repeated ones, show clearly that there were successive stages in the formation of lepidolite.

Mt. Coahuila and in the Anita Mine near Red Mountain. [This occurrence was not filled in on the retyped manuscript]

At Mesa Grande the characteristic form of lepidolite is as isolated crystals and large plates intergrown with muscovite; it is found as such in both the San Diego and the Himalaya Mines. It also occurs here in the various other forms noted and is fairly abundant at both these mines. It was also obtained from the Esmeralda mine.

The most perfect crystals are found in the Little Three mine at Ramona, where aggregates of large crystals were collected (Plate XXXVII H). The mineral also is present, in small amounts as coarse granular aggregates of irregular scales. Lepidolite was reported from Banner and Corona in Riverside County.

Occurrence.

Lepidolite is found only in the middle part of the pegmatite dikes. A few instances were noted where small vein-like off-shoots from the middle part penetrated the upper part of the dike. These off- shoots, though located in the upper part of the dike, belong genetically to the middle part and filled fissures formed after the upper part had, at least in part, consolidated to a firm mass.

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The associated minerals of lepidolite are those found in the middle part of the dike. It is, however, possible to classify these into two groups, namely, those found abundantly with lepidolite and forming a characteristic association with it and, secondly, those seldom found with it.

The abundant and characteristically associated minerals of lepidolite are albite, in tabular crystals (the typical cleavelandite variety), and red and green tourmaline; somewhat less abundant are quartz, massive and in good crystals, microcline, and muscovite in large plates; as rare associates are bismuth, and its secondary alteration products, cassiterite, stibiotantalite, (possibly columbite), microlite, garnet, topaz, and beryl. Cookeite is an abundant coating on many lepidolite specimens; more rare as coating are red and brown iron oxides, black manganese oxide, stilbite, and pinkish clays (halloysite?). The following minerals have been observed enclosed in lepidolite: pink and green tourmaline, muscovite, and black hexagonal mineral from Ramona resembling magnetite in appearance. Lepidolite has been found completely enclosed in quartz, microcline, muscovite, and montebrasite (amblygonite). A characteristic association, in which lepidolite (usually in hexagonal crystals more or less well defined) and some other mineral have mutually penetrated each other to various extents, is represented by albite, microcline, pink tourmaline. Basically then, there are a number of very characteristic associations that have been found at different localities and which resemble each other very closely, but these can be divided into a number of types of forms.

Lepidolite occurs in three distinct forms in California. Each of these shows such variations that they can be subdivided into several groups. The different forms observed are as follows

1. Scaly masses.
a.   Fine grained, compact, nearly pure.
b.   As a rock constituent.
c.   Coarse, granular.
d.   Imperfect crystals.
2.   Large plates, without definite crystal outline.
a.   Large scales.
b.   Border on muscovite.
3.   Distinct crystals.
a.   Simple crystals.
b.   Distorted, elongated crystals.
c.   Compound twinned crystals.

A granular mixture of fine-grained lepidolite and albite with small but very varying amounts of quartz and tourmaline is abundantly found at the Stewart mine and to a less extent at the other mines at Pala. Similar masses were noted at Mesa Grande. Where the constituent minerals are finer grained, they seem to have separated more, and the result is a conglomeration of small masses of lepidolite, tourmaline, albite, and quartz, instead of a granular mixture of these minerals.

A coarser grained phase is likewise abundantly found at the Stewart. Tourmaline Queen, Tourmaline King, Pala Chief, Katerina, and other mines at Pala and to a much less extent at Mesa Grande and other places. This phase consists of a cavernous, open, granular aggregate of violet lepidolite, albite, and pink tourmaline, all in fairly well developed crystals, which reach a length of a centimeter and are seldom less than 3 mm long. This association makes exceedingly handsome specimens because of the good development of crystals and the striking contrast of color.

A phase, abundant at Mesa Grande, but not so common at Pala, is where lepidolite forms small veins in one of the other minerals, usually a feldspar. These veins, seldom more than 1 or 2 cm thick and extending for a 10 cm or more, are filled by a compact mass of lepidolite scales, or more rarely, of well- developed, complexly twinned crystals. Other minerals are absent.

Lepidolite also occurs in large isolated crystals, hexagonal in shape and built up of innumerable twinned scales. These are nearly always attached to either microcline or to tourmaline crystals. (Plate XXXVII G) The large plates without definite crystal boundaries, are embedded in massive quartz and have as common associates muscovite (usually intergrown in parallel position), microcline, albite, and blackish-green, and yellowish-green, and pink tourmalines.

Many other associations are noted but do not seem to be so abundant as those enumerated.

Fine-grained compact scaly masses of nearly pure lepidolite are very abundant. They form either small or very large deposits when they become of value as an ore of either. Only one such body large enough to be of economic importance-- the one in the Stewart Mine, at Pala is known in California. Two others have been reported as being large enough to warrant extraction -- one on Hiriart Hill and one at Banner. Smaller masses are scattered irregularly through the middle part of the pegmatite and grade into the distorted, elongated crystals and compound twinned crystals. An illustration of the typical compact fine-grained lepidolite is shown in Plate XXXIII A. This forms the ore of lithia when pink tourmaline and other accessory minerals are not too abundant.

When the accessory minerals become so abundant as to make the mining of the lepidolite unprofitable, it forms a rock, about one half of which is lepidolite. This rock extends for considerable distance at places. In the Stewart mine, at Pala, it has been traced for over 200 feet.

Coarse granular lepidolite is very abundant, though in quantity it is much less than the fine- grained variety. It also occurs in much smaller masses and is generally associated with so many other minerals-feldspar, tourmaline, quartz--that it has no commercial value. The various colors and shades in which it occurs and the presence of the associated minerals make this form of lepidolite desirable as specimens, and it is, therefore, the form that is most widely distributed in collections.

In many specimens of the coarser lepidolite there is an evident tendency to assume its regular crystallized shape, and this tendency manifests itself in the production of more or less perfect hexagonal scales. These are generally bounded by rough and dull surfaces, seldom plane, and too imperfect for crystal measurement. These imperfect crystals may reach a diameter of a centimeter and a thickness of several millimeters, though these dimensions are a maximum.

Large plates of lepidolite, without any definite crystal outline, are not common but were noticed on several specimens from Pala and from Mesa Grande. They form thin plates embedded in the feldspar or quartz, or they have the characteristic wedge shape, thick at one end and tapering gradually to an edge at the other end. In structure they are similar to the usual wedges of muscovite found in pegmatites throughout the world. Microscopic examination of the polished side of such a wedge of lepidolite shows that it consists of numerous parallel plates of unequal length, as diagrammatically illustrated in figure 133.

FIGURE 133.-Structure of wedge of lepidolite plates. Himalaya mine, Mesa Grande.

Borders of lepidolite on muscovite are very common in this area and good examples were noted at several mines, particularly at the Tourmaline Queen, Pala Chief, and Hiriart mines, at Pala; Himalaya and San Diego mines, at Mesa Grande; and at the Dyche mine, at Oak Grove. The lepidolite forms either a very narrow border on the muscovite (Plate XXXVII C), or it is much broader and forms an important portion of the entire crystal. These intergrowths are described in a later section on page 000.

Simple distinct crystals of large size were obtained in quantity from the Little Three mine, at Ramona. These crystals are aggregates unmixed with any other mineral and were found loose in some of the cavities of the pay shoot. The individual crystals reach a very large size, many of them several centimeters across. A photograph of a group of these large crystals is shown in Plate XXXVII G. They are fairly translucent and show the different crystal faces fairly well. An aggregate of smaller but more sharply defined crystals is shown in Plate XXXVII H. These crystals are very well developed and show many brilliant terminal faces, which permitted a definite determination of the crystallography of lepidolite. By using the results obtained on these crystals, the few terminated crystals found elsewhere (particularly at Pala) could be interpreted.

It is worth noting that the well-developed simple crystals of lepidolite do not occur isolated as in other mineral species like garnet, but that they always form aggregates of dozens-perhaps hundreds-of distinct crystals, free from any other mineral.

Distorted, elongated crystals were noticed on a few specimens. They are similar in shape to those of pink muscovite as described by Bowman[174] on material from Haddam Neck, Connecticut, and as found in the Anita mine, Riverside County, but in California the elongated lepidolite crystals have been found only as isolated crystals and not as a border on another mica.

Compound hexagonal twinned crystals are fairly abundant and are particularly well developed at Mesa Grande. Plate XXXVII F shows a group of such crystals (from the Himalaya mine, at Mesa Grande) attached to a pink tourmaline. A group of similar but smaller crystals from San Pedro mine, Hiriart Hill, at Pala, is shown in Plate XXXVII E. These compound crystals also occur isolated and embedded in large potash-feldspar crystals. A few crystals from the Himalaya mine were pierced by a slender pink tourmaline. Much more commonly these crystals are attached to the sides of a larger pink tourmaline.

PLATE XXXVII. Micas.

A.   Muscovite with centimeter-wide border of lepidolite, around which is a millimeter-wide border of later muscovite. Natural size. Dyche mine, Oak Grove.

B.   The same held in the blast flame for a short time. The muscovite core (white) and outside narrow border of later muscovite (white) are unfused. The lepidolite border (dark) has fused to a slaggy mass. Described on page 000.

C.   Muscovite with narrow border of lepidolite. Tourmaline Queen mine, Pala. Natural size. Compare with Plate XXXVI.

D.   The same held in the blast flame for a short time. Compare remarks under B. Described on page 000.

E.   Group of short prismatic crystals of lepidolite. San Pedro mine, Hiriart Hill,

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[174] Bowman, H. L., On an occurrence of minerals at Haddam, Connecticut, USA: Mineral. Magazine, vol. 13, p. 98. 1910.

Pala. Natural size. The crystals are repeatedly twinned. Described on page 000. Specimens A to E were collected by the writer and are now in the United States National Museum.

F. Group of stout prismatic lepidolite crystals clustered on a elbaite crystal, Himalaya mine, Mesa Grande. Enlarged two times. See page 000.

G. Group of large lepidolite crystals, Little Three mine, Ramona. Natural size. The crystals are not so perfectly developed as those shown in H, which they resemble in habit. They are slightly translucent. See page 000. Specimens in F and G are in the Harvard University mineralogical museum (the A. F. Holden collection.)

H. Group of well-formed lepidolite crystals such as form the basis of the crystallographic description given on pages 000 to 000. Little Three mine, Ramona. Natural size. Collected by the writer and now in the United States National Museum.

I. Rounded short prismatic crystals of muscovite on microcline. Surprise mine, Ramona. Natural size. Described on page 000.

J. Similar muscovite crystals on schorlite. Surprise mine, Ramona. Natural size. Described on page 000 .

Crystallography

Orientation.

Crystals of lepidolite have hitherto not been found in such perfect development that their angular values could be accurately determined; but the crystals from the Little Three mine, at Ramona, are sufficiently well developed for that purpose.

Before entering upon the description of the lepidolite crystals, a brief review is given of the results obtained on the other species of the mica group. Muscovite and biotite are the only species on which exact measurements have been made, although the forms present have been determined on several additional species.

Two orientations have been proposed for the micas, either of which has certain advantages over the other. The two orientations are the well-known ones in which the form M is either the unit prism {110} (β then is about 85°) or the pyramid {221} (β then is nearly 90°). The symbols of the common and the less common forms given above are as follows in the two orientations:

	c	b	o	u	M	e	y	x	z	H	N	Q	h
I	001	010	111	111	110	011	021	131	132	100	130	391	301
II	001	010	112	111	221	023	043	131	131	201	261	130	100

The transformation symbol is the following equation:

$$pq \text{ (old)} = \frac{3p}{p-2} \cdot \frac{3q}{p-2} I.$$

The common forms have much simpler indices in the first orientation; the less common forms are about equally simple. The first orientation is, therefore, chosen.

The crystal forms observed on the several mica species, as given in Dana's System of Mineralogy, Sixth edition, with those determined on the California lepidolite, are as follows:

Muscovite:	c b e y g o M u N x		
Biotite:	c b M o u e r y Q and many other rare forms.		
Lepidomelane:	c b H y o M u		
Zinnwaldite:	c b H o M u x		
Manganophyllite:	c b M o u		
Phlogopite:	c b M o u		
Lepidolite:	c b N h e o u x z Q H		

The percentage of occurrence of these forms for all the species is as follows:

Percentage of occurrence of forms for the mica species.

Form	Occurrence percent	Form	Occurrence percent
c	100	y	43
b	100	x	43
c	100	z	43
u	100	H	43
M	71	N	29
e	57	Q	29

The common forms for the whole mica group are, therefore, c b o u M e and the less common ones are y x Z H N Q h.

Calculation of elements.

The elements of lepidolite were calculated from the four interfacial angles:
c {001} ∧ 0 {111}; b {010} ∧ 0 {111}; c {001} ∧ u {111}; b {010} ∧ u {111}.
The values obtained are a : b : c = 0.5774 : 1 : 2.2029, β = 85° 36'.
For comparison the axial ratios of the other species are given in the following table:

Axial ratios of species of the mica group.

Mineral species	a axis	c axis	β
Lepidolite	0.5774	2.2029	85° 36'
Muscovite	0.5774	2.2175	84° 55'
Biotite	0.5774	2.1932	84° 58'

Calculated to the orientation as given by Dana for the micas, the axial ratio of lepidolite becomes a : b : c = 0.5774 : 1 : 3.2949, β = 89° 23'.

The angles from which the axial ratios of lepidolite were calculated, are as follows:

c {001} ∧ 0 {111}= 73° 37'	c {001} ∧ u {111} = 80° 50'.
b {010} ∧ 0 {111} = 61° 22'	b {010} ∧ u {111} = 60° 23'.

The angle b {010} ∧ c {001} was measured as 90° 00'.

The value for the a-axis (= tan β = tan 30° 00') was obtained as the average of the two sets of measurements:

b ∧ 0 = 29° 58'   c ∧ 0 = 29° 58'
c ∧ u = 30° 02'   b ∧ u = 30° 02'

The angles measured. which yielded the average values from which the axial ratios were calculated, are shown in the table below.

Measured angles from which the elements were calculated.
(Abbreviations: Refl., reflection; ex., excellent; g., good; f, fair]

c {001} ∧ o {111}			b {010} ∧ o {111}			c {001} ∧ u {111}			b {010} ∧ u {111}		
Crystal No.	Refl.	Angle	Crystal No.	Refl.	Angle	Crystal No.	Refl.	Angle	Crystal No.	Refl.	Angle
2	ex.	73°29'	2	g.	61°16'	1	f.	81°12'	3	g.	60°41'
2	ex.	73°31'	44	g.	61°26'	3	g.	80°14'	6	f.	60°24'
6	g.	73°30'	46	g.	61°24'	5	g.	81°02'	9	g.	60°20'
6	g.	73°35'				6	g.	81°26'			
9	ex.	73°37'				8	f.	81°18'	9	g.	60°19'
9	g.	73°42'				9	ex.	80°46'			
9	ex.	73°34'				9	g.	80°42'	10	f.	60°00'
10	g.	73°34'				9	g.	80°49'	44	g.	60°35'
10	g.	73°33'				10	g.	80°46'			
10	g.	73°46'				11	g.	80°55'			
11	g.	73°40'				11	f.	80°43'			
13	g.	73°47'				13	g.	80°31'			
13	g.	73°36'				13	g.	80°37'			
13	g.	73°41'				13	f.	80°42'			
13	g.	73°45'				13	g.	80°48'			
13	g.	73°39'				15	g.	80°51'			
15	g.	73°46'				16	g.	80°56'			
15	g.	73°27'				18	g.	80°44'			
16	g.	73°50'				20	g.	80°52'			
20	g.	73°33'				20	g.	80°55'			
20	g.	73°45'				44	f.	80°55'			
20	g.	73°35'				44	g.	80°55'			
44	g.	73°38'				45	f.	81°12'			

It will be at once noticed that there is a large discrepancy in the number of measurements of the angles between the pyramids and the base c {001} and the brachypinacoid b {010}. This is owing to the fact that the zone could be accurately adjusted on nearly every crystal because of the many faces in this zone and to the further fact that in most cases at least one of these faces would be striated in this zone. Although these striations were detrimental to accurate measurement of the striated face, they were of the greatest assistance in the adjustment of the zone. On the other hand, the zones boo'b' and buu'b' showed only two forms and generally only

two faces could be used for adjustment, so that in nearly all cases it was not certain that the particular zone was accurately adjusted. Hence, the paucity of accurate measurements from b {010}. The clinopinacoid itself was seldom free from striations, which increased the difficulty to accurately place the form in any zone other than that of cb.

Forms and angles.

The list of forms observed on the crystals of lepidolite is as follows, only those determined on the crystals from Ramona being considered established.

c {001}	N {130}	o {111}
b {010}	h {301}	u {Ī11}
a {100}	e {011}	u {Ī11}
		z {131}
x {Ī31}		
Q {391}		

The average of the measured interfacial angles are summarized in the following table, to which are added the calculated values.

Measured and calculated interfacial angles.

Angle		Measured	Calculated
C Λ b =	{001} Λ {010}	89°58'	90°00'
C Λ a =	{001} Λ {100}	85°14'	85°36'
C Λ N =	{001} Λ {130}	87°25'	87°48'
C Λ h =	{001} Λ {301}	89°24'	89°23'
c Λ e =	{001} Λ {011}	65°34'	65°31'
C Λ 0 =	{001} Λ {111}	73°37'	73°35'
C Λ U =	{001} Λ {Ī11}	80°50'	80°55'
C Λ Z =	{001} Λ {131}	79°59'	80°21'
C Λ X =	{001} Λ {Ī31}	84°37'	84°41'
C Λ Q =	{001} Λ {391}	90°36'	90°43'
b Λ N =	{010} Λ {130}	29°57'	30°01'
b Λ e =	{010} Λ {011}	24°26'	24°29'
b Λ 0 =	{010} Λ {111}	61°22'	61°17'
b Λ U =	{010} Λ {Ī11}	60°23'	60°21'
b Λ Z =	{010} Λ {131}	32°03'	31°18'
b Λ X =	{010} Λ {Ī31}	30°27'	30°22'
b Λ Q =	{010} Λ {391}	30°09'	30°22'

The following table gives the calculated coordinate angles ϕ and ρ for the forms of lepidolite.

Coordinate angles for lepidolite.

No.	Letter	Symbol	φ	ρ
1	c	001	90° 00	4° 24'
2	b	010	0° 00'	90° 00'
3	a	100	90° 00'	90° 00'
4	N	130	30° 01'	90° 00'
5	h	301	90° 00'	84° 59'
6	e	011	2° 00'	65° 36'
7	X	131	30° 30'	82° 34'
8	0	111	60° 30'	77° 24'
9	z	131	29° 31'	82° 30'
10	u	T11	59° 30'	77° 02'
11	Q	391	59° 57'	88° 33'

c{001} ∧ b{010}. The angle between the basal pinacoid and the brachypinacoid could be measured accurately on nine crystals. On six of them the angle was exactly 90°00'. On the other three it differed from 90° by different amounts, two less and one greater than 90°. In other words, there was no regularity in the derivations from 90°. Hence, it is believed that these three variations are not true derivations from 90° but were probably caused by incipient cleavages in the crystal, which would tend to throw the individual parts out of strict parallelism. The measurements obtained are as follows:

Measurement of the angle c {001} ∧ {010}.

Crystal No.	Reflection	Angle	Deviation from 90°
1-	Good	89°37'	-0° 23'
3-	Good	90°00'	0° 00'
4-	Good	90°00'	0° 00'
8--	Excellent	90°00'	0° 00'
9--	Good	9()000'	0° 00'
15--	Excellent	90°00'	0° 00'
17--	Excellent	90°00'	0° 00'
20--	Good	89°51'	-0° 09'
44--	Good	90°11'	+0° 11

c {001} ∧ a {100}. The angle between the two pinacoids, equal to β, could not be accurately measured, as all the faces of the form a {100} are dull and uneven. On crystal No. 9, one face of a {100} is developed as a large fairly even face, though it is too dull to reflect any light. The face was coated with an alcoholic solution of shellac, which when dried, reflected a mass of signals. Measurements of the reflection gave values from 85°02' to 85°29' for the angle c {001} ∧ a {100}. The average value is 85°14'; the calculated value is 85°36'.

c {001} ∧ N { 130}. The faces N { 130} are so rounded and uneven that no accurate measurements could be made of them. The best results obtained are the

following:

Measurements of the angle c {001} ∧ N {130}.

Crystal No.	Reflection	Size of face	Calculation angle
3	Poor	Minute	87° 18'
9	Poor	Minute	86° 33'
10	Poor	Minute	87° 00'
11	Poor	Minute	87° 49'
20	Poor	Minute	88° 27'
Average---			87° 27'

c {001} ∧ h {301}. The angle between these forms could be measured on only four crystals. Though present on nearly all crystals, the face is so dull and rough that it cannot be placed even by such means as "maximum illumination."

On Crystal No. 3, the face was sufficiently bright to allow of its approximate measurement. The angle {001} ∧ {301} was found to be 89° (measured 89° 23').

On Crystal No. 5, the form is present as a bright and polished face -- the only crystal on which such a face of h was observed. The angle between h and c (calculated 89°23') was measured with the following results:

{001} ∧ {301} =	90° 26'	{001} ∧ {301} =	89°26'
90°28'		89°29'	
90°28'		89°23'	
90°24'		89°30'	
90°26'		89°28'	
90°23'		89°29'	
Average-	90°25.5'	Average-	89° 27.5'

On crystal No. 9, the development of the faces was complete enough to measure the angle c ∧ h by orienting the crystal according to the position generally adopted. This could be accomplished by means of the two-circle goniometer.

The crystal was set up in position on the two-circle goniometer. The two clinopinacoids and the bases were used for the first adjustment, and then by means of the clinodomes and the pyramids the crystal was brought into accurate position. Then, the vertical circle was set at 90°00' from the reading on the clinopinacoid, the horizontal circle being at h--(h_o + 90°00'). If the orthopinacoid gave a signal, it would be centered on the cross hairs. A reading was taken and the horizontal circle was then moved until the reflection from the base came into view. The angle {001} ∧ { 100} could thus be accurately measured, even though the face {100} gave no reflection. The base gave an excellent signal and the following are the angles obtained from the readings on the horizontal circle:

```
           89° 24'
23'
23'
24'
23'
23'
23'
23'
23'
23'
Average- 89° 23'
```

This is exactly the value calculated from the elements, and gives the angle {001} Λ {301} in the orientation adopted in this report.

The vertical circle was then revolved exactly 180° and the angle {001} Λ { 100} measured. The angle for the reflection from the base was measured several times with the same result; namely, 90°41', the supplement of which, or {001} Λ {100}, is 89°19'. The crystal was then reversed on the holder so that the angle could be measured from the negative base. It was found that this base did not give a single sharp reflection but a group of them. Even by blocking out a portion of the base, more than one signal always remained. The brightest one was chosen, all of the mineral except the narrow strip nearest the h face being blocked out. Only the angle {001} Λ {100} could be measured, and the value found was 89° 22'.

On crystal No. 32, the face of h could be measured, although its reflection was very poor. The angle {001} Λ {301} was found to be 90°32'; whence, {001} Λ {301}= 89°28'.

On crystal No. 46, a dull face of h gave the poor measurement {001} Λ {301}= 90°45', from which {001} Λ {301}= 89°15'.

Summarizing the measurements of the angle c {001} Λ h {301} the form {301} becomes the macropinacoid {100} in the other orientation) the following result is obtained.

```
Crystal        Measured
3               90° (approximately)
5              89°27 1/2' {001} Λ {301}
5              89°34 1/2' {001} Λ {301}

9              89°23'
9·             89°19'
9              89°22'
32             89°28'
46      -      89°15'
Calculated     89°23'
```

c {001} Λ e {011}. The form e {011} is present on many of these crystals, generally as a line face so narrow as to give no reflection but only a bright illumination. On six of the crystals it was broad and even enough to yield a measurable signal. The reflection could be called good, however, on only one crystal.

Measurements of the angle c {001} Λ e {011}.

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Crystal No.	Reflection	Size of face	Calculation angle
1-	Fair	Line face	65° 21'
3-	Poor	Line face	65° 32'
4--	Poor	Line face	65° 43'
4-	Poor	Line face	65° 00'
9--	Good	Minute	65° 35'
12-	Poor	Line face	65° 46'
20-	Poor	Line face	65° 49'
Average-			65°31'

c {001} ⋀ x {Ī31}. The faces of x are both small and large, and the reflection is likewise poor and rarely good. The values obtained are as follows, those measurements where no distinct signal was seen being omitted:

Measurements of the angle c {001} ⋀: x {Ī31}.

Crystal No.	Reflection	Size of face	Calculation angle
1	Poor	Small	83°17'
4	Poor	Small	85°00'
4	Poor	Small	84°30'
5	Poor	Small	84°31'
10	Poor	Small	84°55'
10	Good	Small	84°23'
11	Poor	Small	84°19'
13	Good	Small	85°07
13	Poor	Small	84°07'
14	Poor	Medium	85°30'
15	Good	Minute	84°29'
17	Poor	Large	85°05'
30	Poor	Large	85°39'
37	Poor	Small	84°24'
Average-			84°18'

c {001} ⋀ z {Ī31}. The form z {Ī31} is a rare one, having been observed on only three crystals. The measurements are as follows:

Measurements of the angle c {001} ⋀ z {Ī31}.

Crystal No.	Reflection	Size of face	Calculation angle
1	Good	Large	81°12'
4	Good		80°24'
20	Poor		79°34'
Average-			80°21'

c {001} ∧ Q {391}. The faces of Q were all too poor for exact measurement.

Description of forms.

c {001}. The basal pinacoid is large, smooth. and bright, and if not affected by cleavage or by parallel growth it reflects a single percent image as shown in figure 134. It is, therefore, a most useful face to measure from and was always employed. The face can be used as the pole of the crystal in the preliminary orientation of the crystal on the goniometer, as, in the position taken by Dana (M= {221}, etc., the β is nearly 90°. The perfect basal cleavage of the mineral was often invoked to yield a single plain surface to measure from and generally proved very serviceable.

The base is the intersection of the two zones of striations on lepidolite, namely, *cou* and *ceb*, though in itself it shows no striations.

b {010}. The clinopinacoid varies in size from a small nearly square face to a large rectangular one. On some crystals it is plain, yielding a single image, though more frequently it is striated in the zone *cb*. On a very few crystals these striations cause the face to become considerably rounded. The form is present on all crystals.

a {100}. The orthopinacoid is dull and uneven on all of the observed crystals. It gave no reflection on the goniometer, but its angular inclination was measured by coating the best developed face with shellac, as already described. The boundary line between a and the faces of the unit pyramids is in detail very irregular and the faces of a have the appearance of having been attacked and partly dissolved.

The prism N {130}, perhaps recognized more readily by its indices in the other orientation, namely {261}, is always small and rounded, though usually having a very high polish. It was determined on five crystals but is doubtless present on many more. A path of light such as is shown in figure 134 and not a single signal is reflected by the faces of N. The zone radiating from the base in which N lies is the only other radial zone on these crystals, the more important one being the unit zone {001} ∧ {111} ∧ {110}. In the zone cN lie also x, z, and Q. The indices of these forms, written so as to be easily compared are {390}, {393}, {001}, {393}, {391}, and {390}.

FIGURE 134.-Character of reflections given by different forms of lepidolite. A, perfect signal is given by c {001}, also bheouz; B, signal given by the rounded faces of N {130}; C, mass of signals given by irregular faces of x {$\bar{1}$31}.

h {301}. The dome h, the orthopinacoid in the other orientation, is small and generally dull, being bright and highly polished only on one crystal. The form was observed on four crystals.

e {011}. The clinodome is always very narrow, generally being of the form termed a line face. On crystal No.9 it is wider (direction {001} ∧ {010} than long (direction a axis), but on all other observed crystals the reverse dimensions obtain. It is present on about half the crystals measured.

o {111} and u {111}. The unit pyramids are very similar in character, many of

them yielding perfect reflections free from any striations. Many other are considerably striated in the zone c or u, and give a long series of reflections. In a preliminary note on these crystals by the writer[175] several doubtful forms were pointed out as lying in this zone, but further study has shown that these forms are too uncertain to warrant any description. They probably represent only broad striae in this zone.

x {Ī31}. The faces of x are irregular and composed of a multitude of nearly plane surfaces, no two of which seem to have exactly the same position. As a result the faces yield a mass of signals as shown in figure 134.

z {Ī31}. The faces z are large on some crystals and very narrow on others, all gradations in size having been observed. The reflections were mostly poor. The form is a rare one having been measured on only three crystals.

Q {391}. Only a single minute face of Q was observed. It gave a very poor reflection.

Combinations.

The combinations observed on the lepidolite crystals from California are grouped according to locality. It must be remembered that the crystals measured were not always complete, and if a form be not given in the combination it does not necessarily follow that that the particular form was absent on the original complete crystal, for it may well have been present on that portion which was lacking when the crystal was measured.

Combinations on lepidolite crystals from Ramona.
--- indicates the form is not present

Crystal No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Notebook No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	30	44	45	46
c {001}	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
b {010}	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
a {100}	--	--	a	--	a	a	a	a	a	--	a	--	--	--	--	a	a	--	--	--	a	--	--	a
N {130}	--	--	N	--	--	--	--	--	N	N	N	--	--	--	--	--	--	--	--	--	N	--	--	--
h {301}	--	--	h	--	h	h	h	h	h	--	h	--	--	--	--	h	h	--	--	--	h	--	--	h
e {011}	e	--	e	e	--	--	--	e	e	e	--	e	e	e	--	--	--	--	--	e	--	--	--	--
o {111}	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
x {Ī31}	x	--	--	x	x	x	x	x	x	x	x	--	x	x	x	x	x	x	x	x	x	x	x	x
μ {Ī11}	u	--	u	u	u	u	u	u	u	--	u	u	u	u	u	u	--	u	u	u	u	u	u	u
z {131}	z	--	--	z	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	z	--	--	--	--
Q {391}	--	--	--	--	--	--	--	--	Q	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

The combinations observed on measured crystals from the Tourmaline Queen mine are as follows:

Combinations on measured lepidolite crystals, Tourmaline Queen mine.

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[175] Schaller, W.T., Mineralogical Notes, 21. Crystallography of lepidolite. U.S. Geol. Survey Bull. 262, p. 143, 1905.

Dashes --- indicate the forms were not present]

Crystal No.	Notebook No.	Color	c {001}	b {010}	a {100}	x {$\bar{1}$31}	z {131}	o {111}	μ {$\bar{1}$11}	N {130}
1	21	violet	c	b	a	x	z	--	--	--
2	23	violet	c	--	--	--	--	--	u	N
3	25	violet	c	--	--	x	--	--	u	N
4	26	violet	c	b	--	x	--	--	--	--
5	27	violet	c	--	--	x	--	o	--	--
6	33	violet	c	b	--	x	--	o	--	--
7	38	violet	c	--	--	x	z	--	--	--
8	29	purple	c	b	--	x	z	o	--	--
9	29	purple	c	b	--	x	--	o	--	--

Besides the crystals enumerated, numerous others showed the combination cx, also cxb, and cxba, especially from the Tourmaline Queen and the Pala Chief mines.

Impression forms.

On several crystals, notably on No. 9, occur large faces, smooth and highly polished, which yield perfect reflections on the goniometer. The angles measured indicated that the symbols of these forms were exceedingly complex; in fact, they did not agree well with the angles calculated for any set of indices. Neither did any of the faces lie in zonal relation with the remaining forms of lepidolite.

Further study of these faces showed that they were impression faces caused by a large face, generally the base, of a second crystal being pressed against the growing crystal. They are, therefore, not true crystal faces, but are so abundant as to call especial attention to themselves.

Habit.

The crystals of lepidolite may be grouped under one of four distinct habits. All gradations exist between these, especially between the first two. The habits are named in the order of their relative abundance:

(1) Thin tabular-very abundant; (2) thick, nearly equidimensional--common; (3) short prismatic-rare, confined to complex twins; and (4) thin, long prismatic, almost needlelike--rare.

Habit 1.　　Thin tabular. Crystals of this habit are, as stated, very abundant and make up the majority of the well-defined crystals. Most of the crystals from Ramona belong to this habit. A group of such crystals is shown natural size in Plate XXXVII H, the specimen represented being in the National Museum at Washington. A similar group of tabular crystals, even larger than those just mentioned, is shown natural size in Plate XXXVII G, the specimen belonging to the Holden collection in the Harvard Museum. Several of these crystals, viewed parallel to the base, are translucent.

A frequent combination observed on these tabular crystals is shown in figure 135. Other combinations are shown in figures 141 to 145. A marked characteristic of these tabular crystals is for several individuals having a different development of the same forms to be superimposed one on the other in position parallel to the base. Optical tests showed that these were not twins but simply parallel growths. The marked differences in development of the forms is very striking and is illustrated in the

orthographic projections of figure 136.

FIGURE 135.-Combination of thin tabular crystal. Little Three mine, Ramona. Forms:c {001}, b {010},o {111}, u ($\bar{1}$11).

FIGURE 136.-Orthographic projection of lepidolite crystals showing different development of the same forms In a parallel intergrowth of several individuals. Little Three mine, Ramona.

This same tabular habit was also noticed frequently at other localities, as at Pala and Mesa Grande, though it seemed to be much more prevalent at Ramona.

Habit 2.　　Thick, nearly equidimensional. Short stout crystals having nearly the same diameter in all directions, were noticed at nearly all the localities. The blue and purple lepidolites from the Tourmaline Queen mine, at Pala, which were analyzed, are of this habit. Many similar crystals were noticed at Ramona. Figure 144 shows a similar examples. Some of the short prismatic complex twins, grouped under habit 3, are nearly equidimensional and could as well be placed here. It is to be noted that twins of habit (1), where the composition face is the base c {001}, simulate the nearly equidimensional forms of habit 2, although each unit of the twin belongs to the tabular crystals of habit 1.

Habit 3.　　Short prismatic. In a crystal of this type the vertical axis is longer than the thickness and the habit is thus intermediate between habit 1 and habit 4. The crystals present such unusual features in other ways that it seemed best to place them in a group by themselves. All the crystals of this habit consist of an innumerable number of twinned units, as described on page 000. Not a single untwined crystal belong to this habit was observed, though they may, of course, occur, even in abundance. 173 Crystals of this habit are abundant at Mesa Grande, and Plate XXXII D shows a group of such crystals attached to a pink tourmaline, the specimen belonging to the Holden collection at Harvard. A similar group of crystals from the San Pedro mine, at Pala, is shown in Plate XXXVII E.

Habit 4.　　Thin. long prismatic. The almost needlelike crystals of this habit are rare though they have been observed in minute quantity at several places. The localities are Pala Chief mine, at Pala; Himalaya mine, at Mesa Grande; and White Cap claim, at Coahuila. The shape of the crystals is shown in figure 137. The faces are so dull that it is difficult to interpret them correctly, but in view of the optical tests, it seems likely that the interpretation given is the correct one.

FIGURE 137. Long prismatic lepidolite crystals of the fourth habit. Forms: c {001}, and x {$\bar{1}$31}.

These crystals of the fourth habit may also be considered as one of two extremes of habit--the other being the thin tabular crystals of habit 1. All crystals may then be considered as belonging either to one of the two extremes or to some intermediate member.

Twinning.

The lepidolite crystals are twinned in several different ways, which for convenience of description may be grouped as follows:

1. Twin consists of a small number (not more than six) of units.
    a.　　Composition face, parallel to the base c {001}.

b.   Composition face nearly normal to the base c {001}.

2. Twin consists of an (infinite) number of units.

Crystals 1.a. Only a few crystals were observed in which two units, in twin position, had the base c {001} as the composition face. The forms were so rounded as to make their definite determination impossible but they had the general appearance of figure 3 for muscovite and figures 3 and 4 for biotite, as given in Dana's System of Mineralogy, Sixth edition, on pages 614 and 628, respectively. The two interference figures inclined at 60° to each other afforded the further verification of the twinned character of these crystals. They were observed only from Ramona, though doubtless similar twins occur elsewhere. Infrequently, twins of similar character, but formed of two partly superimposed plates, as described and illustrated by Rogers[176] were also observed.

Crystals 1.b. The twinned groups, consisting of a small number of units, with the composition face nearly normal to the base c {001}, were not observed on the specimens from Ramona but are very abundantly developed on those from Pala, notably on those from the Tourmaline Queen and the Pala Chief mines. They are also to be found at many other places.

The twins consist of two, three, or six units. At Pala and at Rincon, according to Rogers, the habit of the twins is determined by the faces of {131} and the crystals have the appearance shown in figure 138, which shows one composed of two, three, or six units. The composition plane is approximately normal to the base. The average of measurement of the angles c {001} ∧ c {001} gave a value of 1° 26', according to which the twinning plane in the zone (001) ∧ (111), is inclined 43' to the base. This would correspond to the form {331} (or {110} in the other orientation) being the twinning plane. The crystals with the form {131} are prominently developed at Pala; on the other hand, the crystals from Mesa Grande have their shape determined by the form {111}. A twin of six units, similar to the one shown in figure 138 D, but bounded by {111}, has the appearance shown in figure 139.

FIGURE 138.-Lepldolite twins, habit of crystals determined by faces of {131}. A, two units, Pala Chief mine; 8, three units, Pala Chief mine; C, three units, Himalaya mine; D, six units, Pala Chief mine; B and C similar to twins described by Rogers (1.c.)

FIGURE 139.-Twin crystal of lepidolite, Himalaya mine, Mesa Grande.

Crystals 2. Twin crystals consisting of a very large number of units are abundantly developed at Mesa Grande as large hexagonal crystals (Plate XXXVII F), consisting apparently only of c {001}, b {010}, and m {110}. Similar smaller crystals (Plate XXXVII E) are also found at the San Pedro mine, Mesa Grande, and on Hiriart Hill, Pala. As a matter of fact, the base is the only form that can be definitely recognized. Microscopic examination of cleavage plates showed these apparently simple hexagonal crystals to be composed of a very large number of individual units that extinguish at intervals of 30°. Part of these units are bounded by straight lines, forming triangles and rhombs; whereas, others are irregularly rounded areas. A diagrammatic sketch of the appearance of these plates under crossed nicols is shown in figure 140.

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[176] Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego County, California: School of Mines Quarterly, vol. 31, p. 215, 1910.

FIGURE 140.-Lepidolite crystal, twinned. Show innumerable units forming an apparent simple hexagonal crystal, Nicols crossed.

Description of crystals.

The platy crystals are either 4, 6, 8, or 12 sided. The 4-sided ones consist of the combination c {001} and x {$\bar{1}$31} and are shown in figure 141 A. It is to be noted that the combination c {001} and u{ $\bar{1}$ 11} in which the optical axial plane is normal to b {010} would have a perfectly analogous shape; compare figure 141 B. These two combinations could be distinguished by means of the percussion figure. On some of these acute shaped rhombs, faces of b {010} and a {100} are present (figs. 141 C and D).

FIGURE 141.-Acute rhomb shaped crystals of lepidolite. Orthographic projection. A, c {001l}, x ($\bar{1}$31), axial plane-b {010}; B, c {001}, u ($\bar{1}$ 11), axial plane-b {010}, added for comparison; C, c {001}, x {$\bar{1}$31}, b {010},D, c {001},x { $\bar{1}$ 31}, b {010}, a {100}.

On one of the long prismatic crystals from the Himalaya mine, at Mesa Grande, (fig. 142 A), the angle c (001) $\wedge$ x ($\bar{1}$ 31) was measured as 86°56" and c'x' as 86°38' (calculated 00°00'). On a similar crystal (fig. 142 B) from the White Cap mine, near Coahuila, Riverside County, the form h {301} was also present.

FIGURE 142.-Long prismatic crystals of lepidolite Forms: c {001}, x { $\bar{1}$31}, h {301}. A, Himalaya mine, Mesa Grande; B, White Cap mine, near Coahuila, Riverside County.

At the Pala Chief mine, several large crystals of lepidolite, measuring a centimeter or more across and several centimeters long, consist of an aggregate of numerous small parallel rhombic crystals as illustrated in figure 132??. It is believed that these are replacements after muscovite. They are described on p. 000.
Six-sided crystals, either with x {$\bar{1}$31} or u { $\bar{1}$11} and the two faces of a pinacoid, are very abundant. Numerous such crystals were observed from Ramona. Crystal No. 2, (Ramona) as shown in figure 143 is a typical example. Some crystals are much stouter, becoming nearly equidimensional as in figure 144, where two additional small faces are shown. The tabular crystals are also modified as shown in figures 145. The larger development of additional forms, makes the crystals lose their 6-sided appearance and become 8, 10, and 12-sided as shown in figures 146-150.

FIGURE 143.-Tabular lepidolite crystal from Ramona. Forms: c {001}, b {010}, o{111}, u {$\bar{1}$11}. Crystal No.2.

FIGURE 144.-Stout lepidolite crystal from Ramona. Forms: c {001}, b {010}, o {111}, u {$\bar{1}$11}, N {130}, e {011}. Crystal No. 20.

FIGURE 145.-Modified tabular lepidolite crystal from Ramona. Forms: c {001}, b {010}, h {301}, o {111}, u {$\bar{1}$11}, N {130}. Crystal No. 3.

FIGURE 146.-Lepidolite crystal No. 1. Ramona. Forms: c {001}, b {010}, o {111}, .u {$\bar{1}$11}, z {131},x {$\bar{1}$31}.

FIGURE 147.-Lepidolite crystal No.5. Ramona. Forms: c {001}, b {010}, h {301}, o {111}, .u { ī11}, z {131} ,x { ī31}.

FIGURE 148.-Lepidolite crystal No. 8. Ramona: Forms: c {001}, b {010}, h {301}, o {111}, {ī11}, x {ī31}.

FIGURE 149.-Lepidolite (violet) crystal, Tourmaline Queen mine. Forms: c {001}, b {010}, x {l31}.

FIGURE 150.-Lepidolite crystal No.9. Ramona. Forms: c {001}, b {010}, h {301}, o {111}, u {ī11}, e {011}.

A single large crystal from the Esmeralda mine, at Mesa Grande, measures nearly 3 cm across and, as shown by optical tests, is not twinned. It is bounded by 12 faces on the side--namely, b {010}, a {100}, and faces in the zones {001} : {110} and {001} : {130}, respectively. The abundant apparently hexagonal crystals (Plate XXXVII) are in reality complex twins and have already been described under that heading.

Etching.

Natural etch figures were not observed on any crystals or plates of lepidolite, but artificial etchings may be readily produced by immersing the cleavage flakes in a dilute solution of hydrofluoric acid. The interpretation of the symmetry of these etch figures has been minutely studied by Baumhauer, and the results obtained on the California lepidolites are very similar. They are shown in figure 151.

FIGURE 151.-Etch figures (artificial) on lepidolite

Intergrowths with muscovite.

Intergrowths with muscovite have already been mentioned as abundantly developed in California. At the different deposits, different kinds of intergrowths occur, but it is to be noted that it is always muscovite that forms the core of the crystal.
Well-developed crystals of muscovite showing a lepidolite border were not seen, but imperfect crystals, showing definite crystallographical outline, are abundant. Two such crystals are shown in Plate XXXVII A and C, in connection with a view of a similar cleavage piece that has been held in the blast flame long enough to melt the lepidolite. The different fusibility of lepidolite and muscovite has served as a valuable criterion for distinguishing these two micas.
The intergrowths consist either of a single border of lepidolite on muscovite (Plate XXXVII A), or of a repeated intergrowth that in the best-developed case observed amounted to five successive deposits- -namely, (as the core) muscovite, lepidolite (narrow), muscovite (broad), lepidolite (narrow), and muscovite (narrow). Plate XXXVII B shows a core of muscovite (white unfused) with a border of dark fused lepidolite, around which is a narrow band of white unfused muscovite. The narrow outside border of muscovite can also be seen in the photograph of the unfused specimen (Plate XXXVII A).

Physical properties.

Cohesion.

Lepidolite has a perfect basal cleavage, but no tendency to cleave in any other direction was observed, although on some specimens the parting is so well developed in numerous parallel planes as to simulate cleavage closely.

Parting is well developed only at Mesa Grande in the large mica plates embedded in massive quartz (No. 4 of mode of occurrence of lithium-bearing minerals in the middle part of the pegmatite, page xxx) The parting is very similar to that of the accompanying muscovite. Gliding planes, whose traces show in the basal cleavage as numerous parallel lines, lie in the two zones c {001} : a {100} and c {001} : N {130}. The percussion figures are not so readily obtained on lepidolite as on muscovite, nor are they so perfect.

Density.

The density of numerous specimens of lepidolite was determined by means of heavy solutions and the values obtained are shown in the following table.

Note: Data missing here.

Optical properties.

Color.

The body color of lepidolite depends altogether on the amount of manganese and iron present, especially the former. Manganese is present in all the samples examined and doubtless in all the lepidolites found in the area. and in correlation with this fact none of the lepidolite is white, all of it being colored. On some specimens the coloring matter is so diluted, that the mineral appears almost white but on comparing it with a white mineral (amblygonite, for example) it is readily seen that the mica is colored.

The intensity of the color shows very great variation in different samples, but nearly all of the observed colors can be referred to some shade of purple.

The actual colors observed on the collected specimens are very pale pink-common for the fine- grained scaly aggregates; purple-very common for all phases of the mineral; violet--abundant in the coarsely crystallized aggregates. Various modifications of these colors, such as gray-purple, and blue- violet are observed, as are likewise all combinations of color between purple and violet.

Chemical properties.

Pyrognostics.

Lepidolite is easily fusible before the blowpipe flame, which is colored red by lithium, and this property has a valuable diagnostic character for distinguishing lepidolite from muscovite, which, at places, greatly resembles it. See Plate XXXVII B and D for illustrations showing how the different fusibility of lepidolite and muscovite serves to distinguish the two micas. Heated strongly in a closed tube, lepidolite becomes opaque and loses color, changing to a white or pale pink and fusing somewhat. Practically no water is given off, but the white fluorine ring is always developed. The pyrognostic behavior of lepidolite always serves to distinguish it from

muscovite.

Preparation of samples.

Six different samples of lepidolite were analyzed. The samples were selected so as to include as many different varieties as possible and at the same time to consist of homogeneous and pure material. The different samples are as follows:

Sample No. 1 is the most compact lepidolite found in the entire field. It is the purple mica from the claim known as the "Forty Acres", adjoining the Stewart mine, on Stewart Hill, Pala. Its location is shown in figure 18, where it is referred to as "Ore Body No. 4." It is impossible to be sure of the purity of the sample from the character of the hand specimen, and two thin sections were made and carefully studied. No impurity of any kind could be seen. The analysis showed the highest alumina and the lowest lithia of the lepidolites analyzed. Unfortunately, the material is too fine grained, and the crystals too poorly developed for the determination of optical properties.

Sample No.2 is the border lepidolite from the San Diego mine, at Mesa Grande. It forms a well- defined border about 3 mm wide on large muscovite plates, with which it is in optical continuity. A specimen similar to the one analyzed is shown in Plate XXXVII A shows the lepidolite border, which can be better told from the muscovite in XXXVII B, where the lepidolite has been fused. Microscopic examination of numerous cleavage flakes showed that no non-mica mineral was present. The boundary line between the lepidolite and the pink muscovite was sharply defined, and sufficient pure material, free from muscovite, could readily be obtained for investigation.

Sample No.3 is the compact fine-grained lepidolite "ore" from the Stewart mine, at Pala. This type of material, widely distributed over the world, is shown in Plate XXXIII A. The sample analyzed was selected both as typical of hundreds of tons of ore and because of its purity. The assumed freedom from other minerals was confirmed by the examination of two thin sections.

Sample No. 4 is the violet or blue-purple lepidolite from the Tourmaline Queen mine, at Pala. The mineral occurs in more or less well developed crystals several millimeters thick and having the crystal combination and habit shown in figure 149. These crystals, mostly twinned repeatedly as shown in figure 140, are transparent and pure and represent the most deeply colored variety in the field.

Sample No. 5 is similar to No. 4 in all characteristics except color, for it is more of a true purple, having a decidedly redder tint. It is likewise from the Tourmaline Queen mine. The character of the lepidolite from which samples Nos. 4 and 5 were obtained is such that no difficulty was had in procuring pure material for analysis. An unsuccessful attempt was made to correlate other changes in properties with the changes in color.

Sample No. 6 consists of the large crystals from the Little Three mine; at Ramona; the character of the material is well shown in Plate XXXVII G and the crystals have been described on pages 000. Apparently, the most Suitable for chemical analysis of all the lepidolites, in reality it furnished hardly a good sample of perfectly pure material. This is because clay has seeped in by the cleavages and even the most compact crystals contain minute films of dirt parallel to the cleavage. Determinations of iron and manganese were not made on this sample, as the amount of available material was too small. The results given below are considered the least accurate of the six analyses.

Quantitative composition.

The analyses of the six lepidolites which have been briefly characterized in the preceding paragraphs are given below:

Analyses of lepidolites from California.
---- means oxide not detected W.T. Schaller, analyst]

Sample-	1.	2.	3.	4.	5.	6.
Habit and color--	Compact violet	Purple border on muscovite	Compact lithia ore	Violet crystals	Purple crystals	Large crystals
Locality-	40 acres, Pala	Mesa Grande	Stewart mine, Pala	Tourmaline Queen mine, Pala	Tourmaline Queen mine, Pala	Little Three mine, Ramona
SiO_2	50.34	50.85	51.25	50.95	51.12	51.46
Al_2O_3	28.71	26.78	25.62	24.01	22.74	23.46
Fe_2O_3	0.11	0.60	0.12	0.82	0.80	---
Mn_2O	0.56	0.08	0.06	1.29	1.34	---
Li_2O	2.39	4.27	4.31	4.63	5.12	6.06
Na_2O	1.59	1.41	1.94	2.39	2.28	2.09
K_2O	10.37	10.30	10.65	10.69	10.60	10.71
H_2O	3.15	1.74	1.60	1.91	2.05	1.83
F	5.02	6.71	7.06	6.11	6.38	8.27
Subtotal	102.24	102.74	102.61	102.80	102.43	103.88
Excess O	2.11	2.82	2.97	2.57	2.69	3.48
Total-	100.13	99.92	99.64	100.23	99.74	100.40

These analyses have been arranged in the order of decreasing R_2O_3, that is essentially Al_2O_3. The iron and manganese have been considered as present as sesquioxides replacing the alumina, chiefly because of the strong chromatic effect exercised by these oxides. It could be proved analytically that FeO was not present as such in the mineral and that the iron was in the ferric state. It would then be most simple and consistent to consider the manganese as present in a similar state, and, when the strong colorations produced by the small amounts of iron and manganese present are considered, it seems most locally to treat them both as present with the alumina in the trivalent stage. It is, of course, not at all improbable that most of the iron is admixed hematite which, as minute specks, escaped detection and that both manganous and manganic oxides are present in the lepidolite. When the analyses were made it was customary in the laboratory of the U.S. Geological Survey to determine the manganese gravimetrically. Later verifications were partly made by the colorimetric method, which gave similar results. On the few samples of which the original material was still available the manganese was determined by dissolving the lepidolite in hydrofluoric acid and titrating the manganous fluoride with potassium permanganate. The results calculated as Mn_2O_3 (= MnO + MnO_2) gave values concordant with those previously obtained, so that the assumption made that the

manganese is all present as Mn2O3 seems well substantiated by the experimental results.

Discussion of composition.

Before trying to deduce any formulas from the analyses of the California lepidolites, it is necessary to see if the explanations offered are sufficient to cover the new analyses given. The formula given in most text books is the metasilicate one, (SiO3)3 ·Al·Al(F,OH)2KLi, which may be written in the form 6SiO2 ·2Al2O3·K2O Li2O F4. This is the formula given in text books on mineralogy, such as those by Dana, Hintze, Tschermak, and Naumann-Zirkel. For many of the lepidolites analyzed, the formula fits very well. For others it is impossible. The essential replacements in this formula are those of sodium for potassium and fluorine by hydroxyl. The four possible formulas are then:

(SiO3)3 Al AlF2 K Li, or 6SiO2 2Al2O3 K2O Li2O F4

(SiO3)3 Al Al(OH)2 K Li, or 6SiO2 2Al2O3 K2O Li2O 2H2O

(SiO3)3 • Al • AlF2 • Na • Li, or 6SiO2 • 2Al2O3 • Na2O • Li2O • F4

(SiO3)3 • Al • Al(OH)2 • Na • Li, or 6SiO2 • 2Al2O3 • Na2O • Li2O • 2H2O

Mixtures of these four compounds produce the different varieties of lepidolite found, and, if these formulas suffice to explain the chemical composition, then all lepidolites should be comparable to some mixture of these compounds. The California lepidolites cannot be explained as mixtures of any of these four compounds, as the following tabulation shows. Herein are given the calculated percentages corresponding to these four formulas. In the last column are reproduced the extreme values determined on the California lepidolites.

Comparison of analyses of California lepidolites with values, calculated from four formulas.

	6SiO2 2Al2O3 2O·· Li2O F	•6SiO2 ••2Al2O3 K2O • Li2O ••H2O	6SiO2··2Al2O3 Na2O··Li2O·· F4	6SiO2••2Al2O3 Na2O••Li2O • 2H2O	Extreme •values, California lepidolites
SiO2	49.27	49.81	51.53	52.12	50.34-51.46
Al2O3	27.84	28.14	29.11	29.45	a 23.46-29.14
K2O	12.83	12.97	0.00	0.00	10.30-10.71
Na2O	0.00	0.00	8.83	8.93	1.41-2.39
Li2O	4.07	4.12	4.26	4.31	2.39-6.06
F	10.35	0.00	10.82	0.00	5.02-8.27
H2O	0.00	4.96	0.00	5.19	1.60-3.15
Subtotal	104.36	100.00	104.55	100.00	
Excess O	4.36		4.55		
Total	100.00		100.00		

a Including 0.43 percent of Fe_2O_3 and Mn_2O_3·

The percentages of SiO_2, K_2O, Na_2O, F, and H_2O in the analyses lie between the minimum and the maximum limits of the same percentages in the calculated values. But for Al_2O_3 and Li_2O this is not so. The lowest value obtained for Al_2O_3 is 23.46 percent; whereas, the lowest calculated value is 27.84 percent. The lowest value obtained for Li_2O is 2.39 percent; whereas, the lowest calculated value is 4.07 percent. Similarly, the highest value obtained for Li_2O, namely, 6.06 percent, is much greater than the maximum calculated value 4.31 percent. In fact, half of the six analyses show a higher lithia content than the maximum calculated value.

The explanation of the composition of lepidolite, based on the metasilicate formulas given above, does not then suffice for the lepidolites from California. It is to be noted, however, that many analyses can be explained as mixtures of these formulas, but that for many other analyses the formulas do not suffice.

Dana[177] has suggested the formulas as $R_6Al_2(SiO_4)_3$ + $R_6Al_2(Si_2O_8)_3$, whereas, Clarke[178] prefers the formulas $HKLiAl_3(SiO_4)_3$ + $(AlF_2)_3K_3Li_3Al_3Al(Si_3O_8)_3$, and he considers an average lepidolite as made up of equal amounts of the two compounds for which he calculates the following percentages:

Calculated composition for an average lepidolite, after Clarke, compared with composition of California lepidolite.

Oxides	Calculated composition (After Clarke)	Compact lepidolite, Stewart mine, Pala a	Extremes on California lepidolite
SiO2	51.43	50.96	50.34-51.46
Al2O3	25.50	25.58	23.46-29.14
K2O	13.43	13.50	b 12.44-14.33
Li2O	4.29	4.30	2.39-6.06
H2O	0.64	1.60	1.60-3.15
F	8.13	7.02	5.02-8.27
Subtotal	103.42	102.96	
Excess O	3.42	2.96	
Total	100.00	100.00	

a The small amounts of Fe_2O_3 and Mn_2O_3 have been added molecularly to the Al_2O_3, the Na_2O to the K_2O.and the analysis reduced to 100 percent
b Including the Na_2O.

Clarke's "average lepidolite" agrees very well with the compact "lithia ore" from the Stewart mine and also closely represents the average of the analyses of the California lepidolites, as is shown by comparing his figures with the mean of those

[177] Dana, E.S., System of mineralogy, 6th ed., p. 613, 1892.
[178] Clarke, F.W., The constitution of the natural silicates; U.S.. Geol. Survey Bull. 588, p. 128, 1914

given in the last column. If now Clarke's two compounds represent the composition of lepidolite, it should then be possible to explain all lepidolite analyses as varying mixtures of his two compounds. This cannot be done. The inability of his two compounds to represent all analyses can be well shown by comparing the calculated values of his two compounds with the two analyses of California material that show the greatest difference.

Comparison of analyses of two California lepidolites with the calculated composition of Clarke's two compounds.

| | Clarke's compounds | | California lepidolites a | |
	(AlF2)3K3Li3 Al(Si3O8)3	HKLiAl3 (SiO4)3	40 acres, Pala	Little Three mine, Ramona
Si O2	54.31	44.64	49.99	50.71
Al2O3	20.46	37.83	28.93	23.12
Li2O	4.49	3.69	2.38	5.97
K2O	14.14	11.62	12.69	13.68
F	11.40	0.00	4.98	8.15
H2O	0.00	2.22	3.13	1.80
Subtotal	104.80	100.00	102.10	103.43
Excess O	4.80		2.10	3.43
Total	100.00		100.00	100.00

a The Fe2O3 and Mn2O3 have been combined with the Al2O3, the Na2O with the K2O, and the analyses reduced to 100 percent.

The comparison shows that the two compounds of Clarke do not suffice to explain the composition of all the lepidolites analyzed. The two California micas contain nearly the same amount of Si, but the Al2O3 is very different. The two extremes of Li2O given in the analyses are too low and too high, respectively, to agree \\ith Clarke's compounds.

Scharizer[179] proposed to consider lepidolites as an isomorphous mixture of the pure muscovite- silicate R6Al6Si6O24 with the compound R8Al6Si10(OH,F)6O30. which he called lithionite-silicate (Scharizer uses .the term lithionite for lepidolite).

For the general muscovite formula R6Al6Si6O24, such compounds as H4K2Al6Si6O24, H2K.4Al6Si6O24• and K6Al6Si6O24 are adopted. Mixtures of one of these three muscovite-silicates with his lithionite-silicate R8Al6(OH,F)6Si10O30 are said to yield compositions that agree with the analyses of natural lepidolites. No such comparison of analytical figures was made by Scharizer, so that the question of a possible agreement still remains to be proved. The existence in nature of two of his muscovite- silicates, although theoretically possible, has not yet been demonstrated, nor has the definite existence of his lithionite-silicate been demonstrated, in spite of his claim that the analysis of lepidolite from Schilttenhofen yields this formula. These compounds do not suffice to explain the composition of the California lepidolites, especially the low value of Al2O3 in some of the analyses.

[179] Scharizer, R. The chemical composition of variously colored micas from the pegmatitic granite of Schnttenhofen, Zeitschr. Kryst.. Min., vol. 13, p. 470, 1888.

The theories proposed, then, are not adequate to explain the composition of all lepidolites as shown in the analyses of six samples from California. A study of the analyses of these six samples is, therefore, made in order to see if a satisfactory solution to the problem can be found.

The ratios calculated from the six analyses are as follows:
Ratios of analyses of lepidolite.

Sample No.	1.	2.	3.	4.	5.	6.
Habit and color-------	Compact, violet	Purple border on muscovite	Compact lithia ore	Violet crystals	Purple crystals	Large crystals
Locality---	40 acres, Pala	Mesa Grande	Stewart mine, Pala	Tourmaline Queen mine, Pala	Tourmaline Queen mine, Pala	Little Three mine, Ramona
SiO_2---------	0.8348	0.8433	0.8499	0.8449	0.8478	0.8534
Al_2O_3-------	.2809	.2620	.2507	.2345	.2221	.2295
Fe_2O_3--------	.0007	.0038	.0007	.0051	.0050	- - -
Mn_2O_3-------	.0036	.0005	.0004	.0082	.0085	- - -
Li_2O---------	.0799	.1428	.1441	.1548	.1712	.2027
Na_2O--------	.0257	.0227	.0313	.0385	.0368	.0337
K_2O---------	.1101	.1094	.1131	.1135	.1125	.1137
H_2O---------	.1750	.0967	.0889	.1061	.1139	.1017
F-------------	.2642	.3531	.3716	.3216	.3358	.4353
SiO_2---------	.8348	.8433	.8499	.8449	.8478	.8534
R_2O_3--------	.2852	.2663	.2518	.2478	.2356	.2295
R_2O---------	.2157	.2749	.2885	.3068	.3205	.3501
F(OH)-------	.6142	.5465	.5494	.5388	.5636	.6387

An inspection of the lower part of the table, wherein Fe2O3 and Mn2O3 have been combined with Al2O3, Li2O and Na2O with K2O, and water (as hydroxyl) united with univalent fluorine shows that whereas SiO2 and F remain practically constant, the other two oxides, R2O3 and R2O, vary considerably, and that. moreover, this variation is reciprocal. As the alumina decreases in amount. the alkalies increase. This variation can be better shown by reducing the most constant value, in this case the SiO2, to a rational number (12) and recalculating the other values. The results obtained are shown below.

Recalculated ratios of analyses of lepidolite.

Sample-	1.	2.	3.	4.	5.	6.
SiO2	12.00	12.00	12.00	12.00	12.00	12.00
R2O3	4.09	3.79	3.56	3.52	3.33	3.23
R2O	3.10	3.91	4.07	4.36	4.53	4.92
F	8.83	7.77	7.76	7.58	7.98	8.98

If the reciprocal between R2O3 and R2O is a constant, then the sum of R2O3 + 1/3 R2O should be constant. The following tabulation shows this to be the approximate fact:

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Sample No.----	1.	2.	3.	4.	5.	6.
$R_2O_3 + 1/3R_2O$	5.12	5.09	4.92	4.97	4.84	4.87

These relations have all been deduced on the assumption that the SiO2 is a constant. An inspection of the six analyses on page 000 shows that this is practically true, the maximum difference between any two percentages being 1.12 percent or about 2 percent of the silica. As tabulated, the silica increases slightly with the alkalies, though the amount is too small to justify any claim that such an increase is definitely present. The percentages of silica may, therefore, be considered as constant. The question of the constancy of the silica is, moreover, ·without effect on the ratio of R2O3 and R20, which in itself is of course independent of any other chemical compound.

A further inspection of the analyses on page 000 shows that besides the silica, the potash is also very constant, the maximum difference between two determinations being 0.41 percent. Likewise, the amount of fluorine plus water (or hydroxyl) is also fairly constant, as is shown by the tabulated ratios of the six lepidolites.

The ratio of SiO2 to K2O for the six analyses is as follows:

Sample No.	1.	2.	3.	4.	5.	6.
Rat.io SiO2 = K2O	7.58	7.71	7.51	7.44	7.54	7.51

The average ratio is 7.56, or nearly 7.5.

This would give a ratio of SiO2 : K2O = 12: 1.6, a ratio so complex that it seems unreasonable. By combining the soda with the potash, much better ratios are obtained. The ratio of K2O + Na2O to Si, the SiO2 being taken as 12, is as follows.

Sample No.	1.	2.	3.	4.	5.	6.
Rat.io K2O + Na2O	1.95	1.88	2.04	2.16	2.11	2.07

The average ratio is 2.04. The ratios previously given are now readjusted by making K2O exactly equal to 2.00, enough soda and lithia (if necessary) being added to the potash to make the ratio exactly 2.00. Any excess of soda is then added to the lithia. The ratios so obtained are as follows:

Re-adjusted ratios of analyses of lepidolite.

Sample No.	1	2.	3.	4.	5.	6.
SiO_2	12.00	12.00	12.00	12.00	12.00	12.00
Al_2O_3	4.09	3.79	3.56	3.52	3.33	3.23
K_2O	[a] 2.00	[b] 2.00	2.00	2.00	2.00	2.00
Li_2O	1.1	1.91	2.07	2.36	2.53	2.92
F	8.83	7.77	7.76	7.58	7.98	8.98

a Contains 0.05 Li_2O.
b Contains 0.12 Li_2O

The average of the six ratios for fluorine (with which the hydroxyl has been combined) is 8.15 and the ratio of F to SiO_2 of 8 to 12 is well substantiated by the results given. The three non-variables then, SiO_2, K_2O, and F are in the ratio of 12 : 2 : 8. It only remains to bring the alumina and lithia into accord, and this can best be done by finding the two apparent end products--the one richest in alumina and the one poorest in alumina.

The sum of the ratio of Al_2O_3 + 1/3 Li_2O is essentially constant:

Analyses of lepidolite

Sample No.--------	1.	2.	3.	4.	5.
Al_2O_3 + 1/3 Li_2O	4.46	4.43	4.25	4.31	4.17

The readjusted values of the ratios of Al_2O_3 and Li_2O as just given are plotted as shown in figure 152, where the ratios of the pink muscovite (M') are also added. If the points are joined by a line it is seen that the two end products M and L, respectively, have the ratios:

m = $6Al_2O_3$ • $0Li_2O$
   and
L = $3Al_2O_3$ • Li_2O.

FIGURE 152.-Relation of the ratios of Al_2O_3 and Li_2O, lepidolite. The numbers refer to the analyses given in the text. M' is k muscovite (analysis given on page 000), M and L are the theoretic end products.

As the ratios of SiO_2, K_2O, and F are constant, the two end products whose mixtures yield the different lepidolites, are

M = $12SiO_2$ • $6Al_2O_3$ • $0Li_2O$ • $2K_2O$ • 8F
         and
L = $12SiO_2$ •·$3Al_2O_3$·• $3Li_2O$ • $2K_2O$ • 8F.

The first of these two end products, $12SiO_2$ • $6Al_2O_3$ • $0Li_2O$ • $2K_2O$ • 8F can be written with hydroxyl instead of fluorine. For convenience of calculation, the water in lepidolite has as hydroxyl, been changed to an equivalent amount of fluorine. Now that the type of end product has been determined the fluorine in the formula can be

replaced by hydroxyl and stated as water, and the end product M then becomes 12SiO2 • 6Al2O3 • 0Li2O • 2K2O • 8F, which is the formula of muscovite. One of the two end products whose mixture yields lepidolite is the well known compound muscovite existing abundantly in nature and whose properties are well known.

The second end product L, 12SiO2 •·3Al2O3·• 3Li2O • 2K2O • 8F, is one which, as far as known has not been proposed. The six samples of lepidolite analyzed show the fact that the perfection of the development of the crystals increases regularly with tile variation in composition as shown in the table "Ratios of analyses of lepidolite."

Sample No. 1 is very fine grained and compact, without any development of idiomorphic crystals. Samples Nos. 2 and 3 are much coarser grained, and the mica plates, though still poorly developed crystallographically, show imperfect crystal boundaries.

Samples Nos. 4 and 5 are good crystals for mica and often show well-developed crystals. The crystal forms and the twinning can be well determined on nearly all the crystals of samples Nos. 4 and 5.

Sample 6 is the best-developed lepidolite ever described, and in fact is excelled by few minerals in the completeness and perfection of development. It is to be supposed then that sample No. 6, representing the most perfectly developed crystal, would likewise represent chemically the most perfectly developed, that is the purest lithium mica. This is the fact, for sample No. 6 represents very closely the composition of the second end product, 12SiO2 •·3Al2O3·• 3Li2O • 2K2O • 8F as is shown by the following tabulation:

Chemical relation of lepidolite from Ramona (Sample No. 6)
to theoretic end product 12SiO2 •·3Al2O3·• 3Li2O • 2K2O • 8F

Oxides	analysis	ratio	calculated for 12SiO2 •·3Al2O3·• 3Li2O • 2K2O • 8F
SiO2	51.46	a 12.00	51.82
Al2O3	23.46	3.23	21.96
Li2O	6.06	2.85	6.43
Na2O	2.09		
K2O	10.71	2.07	13.49
H2O	1.83		
F	8.27	8.98	10.88
Subtotal	103.88		104.58
Excess O	3.48		4.58
Total	100.00		100.00

a The value of the SiO2 was arbitrarily taken as 12.00

A small part of the muscovite formula (the first end product) is present, as appears from the ratio for Al2O3 being slightly above 3.00 and that of Li2O slightly below 3.00. The two formulas here proposed as end products whose mixtures yield the different varieties of lepidolite have the advantage over other proposed formulas that they both represent minerals that occur naturally in the pure state. The proportions in which they are present in the six samples of California lepidolites are as follows:

Percentage of two end products M and L in the California lepidolite-

M = 12SiO2 • 6AL2O3 • 2K2O • 4H2O

L = 12SiO2 • 3AL2O3 • 3LiO2 • 2K2O • 8F
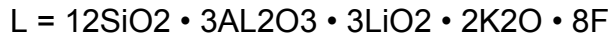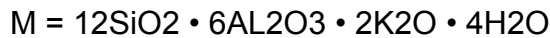
Sample No.	6.	5.	4.	3.	2.	1.
M-	5	13	19	25	31	50
L--	95	87	81	75	69	50

Cookeite

Localities.

Cookeite probably occurs at nearly all the localities from which lithium-bearing minerals have been obtained, but as it is an unobtrusive mineral, it is liable to escape detection unless a careful search is made for it. Much compact muscovite has been called cookeite; so too many pink clays (as halloysite) have been mistaken for cookeite.

The deposits from which cookeite has been definitely determined are as follows: At Pala, the Stewart, Tourmaline Queen, Pala Chief, and Katerina mines; at Rincon, the Victor mine; at Mesa Grande, the San Diego, Himalaya, and Esmeralda mines. Doubtless, other mines should be added to this list that, however, is restricted to those for which the identification of cookeite is conclusive.

Occurrence.

Cookeite occurs only in the pay shoot of the middle part of the pegmatite dikes. Its mode of occurrence strongly suggests a secondary mineral, and it distinctly belongs to one of the later stages of activity of the middle part of the pegmatites and is to be classed under the period of formation of the zeolites.

At the Stewart mine, cookeite was collected from a pocket by Mr. John Reed, who stated that only one pocket had shown any of the mineral. The cookeite forms numerous small spherulites composed of wedge-shaped hexagonal plates that successively deviate slightly from strict parallelism. These spherulites average about one-fourth to one-half of a millimeter in diameter. They coat much larger quartz crystals and are in part entirely embedded in the quartz, (fig. 153).

FIGURE 153.-Relationship of cookeite to quartz crystal. Stewart mine.

The quartz continued to grow after the formation of cookeite had begun but stopped growing before the maximum amount of cookeite had formed. With these quartz crystals are associated elbaite, albite, and lepidolite. Most of the elbaite has disappeared leaving only a small portion of the original crystal in the cavity. The remaining portion is perfectly fresh and transparent, but it is considerably etched, and the suggestion at once presents itself that the elbaite was attacked by solutions and that part of its composition recrystallized as cookeite.

A similar suggestion was made by Penfield[180], who stated that: "*Cookeite is*

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[180] Penfield, S. On cookeite from Paris and Hebron, Maine. Am. Jour. Sci., 3d

associated with quartz, lepidolite, and tourmaline (especially the variety rubellite) and apparently has resulted from the alteration of the latter, as suggested by Professor Brush." One of the best and most interesting specimens of the mineral in the Brush collection is a deposit of the mineral on a large tourmaline crystal. This latter has a triangular prismatic habit, terminated by a basal plane and is over 4 cm in diameter. As a subsequent process the tourmaline has been mostly removed, leaving a cellular interior, containing cookeite, a few quartz crystals, and remnants of the original tourmaline, etched out into slender prisms and spicules reminding one of the etched beryls (aquamarines) from Mt. Antero, Colorado. The cookeite here is plainly a secondary mineral and in this respect, as well as in its crystalline habit, mode of twinning, and optical properties, it is related to the chlorites.

At the Pala Chief mine cookeite is found as a very fine grained clayey looking material coating aggregates of purple lepidolite crystals, red and green tourmaline, and albite. There seems to be two generations of cookeite on these specimens. The first generation from one quarter to one half a millimeter thick consists of imperfectly developed plates, which occasionally show a hexagonal outline. The second generation, more uneven in thickness but with about the same average, is a fine flowery powder, which under a hand lens shows no definite crystallization. The enclosed crystals of tourmaline, lepidolite, and albite are well developed and still show bright unattacked plane surfaces, so that the source of the material yielding the cookeite is not apparent on these specimens. An exceptionally favorable place on the specimen studied is diagrammatically represented in figure 154, in which the secondary character of the relationship of the two generations of cookeite is clearly shown.

FIGURE 154.-Relationship of cookeite to other minerals. T, red tourmaline: L, lepidolite; A, albite; all well crystallized; C, first generation of cookeite; C2, second generation of cookeite.

At the Katerina mine large masses of fine-granular cookeite, altered from spodurnene, were found. Where the kunzite has altered to cookeite, the original shape of the kunzite crystal has not been well retained.

At Rincon cookeite has been described by Rogers as occurring in the pockets of the dike, coating quartz, lepidolite, orthoclase, albite, and kunzite, and as forming the matrix of kunzite. Such a specimen, in the American Museum of Natural History, is shown in Plate XXXII Hand I. Rogers further states:

1   It is clearly a secondary mineral-a pseudomorph of cookeite after kunzite was found. Cookeite is a micaceous mineral occurring in minute rosettes (not over 1 millimeter) or in massive aggregates.

A specimen described by Rogers shows that the formation of the cookeite preceded that of the zeolites. He says:

" In the bottom of a pocket there was found just below a large quartz crystal a thin crust of the same outline which had evidently fallen from it the inside smooth surface of this crust was pink cookeite, while the outside was stilbite. A few isolated stilbite crystals were also found inside the crust. Several crystals of very much corroded kunzite were firmly embedded in the crust and penetrated the inside surface."[181]

ser., vo1. 45, p. 393, 1893.

[181] Rogers, A F., Minerals from the pegmatite veins of Rincon, San Diego County, California: School of Mines Quarterly., vol. 31, p. 216, 1910.

At Mesa Grande cookeite is rather abundant and is frequently found as a coating completely enclosing crystals of tourmaline and more on rarely lepidolite and other minerals, as earlier described by Sterrett.[182] The appearance of these tourmaline crystals, completely enclosed in cookeite, is very striking and two views of such an occurrence appear in Plate XXXII H, wherein is shown a crystal completely covered; a portion of the cookeite has been removed, exposing the underlying tourmaline crystal, which has remained perfectly clear and unaltered.

Optical properties.

The color of most of the cookeite is pink. As stated by Rogers, the "color varies from colorless to deep pink, a yellowish pink being very common." When the small rosettes are crushed and examined under the microscope, the hexagonal shape of the individual crystals can readily be seen. On the specimens from the Stewart mine, these hexagonal plates are either divided into six sectors, all biaxial
with a large angle, or else into a uniaxial central core surrounded by six biaxial sectors, as earlier described by Penfield and shown in figure 155. The axial plane is normal to the basal cleavage and parallel to the sides of the hexagon. 2f is large. Crystals showing the half-hexagonal outline is illustrated by Rogers were not seen by the writer. In the bottom of a pocket there was found just below a large quartz crystal a thin crust of the same outline which had evidently fallen from it. The inside smooth surface of this crust was pink cookelte, while the outside was stilbite. A few isolated stilbite crystals were also found

FIGURE 155.-Optlcal character of cookeite plates.

Chemical properties.

Pyrognostics.

The pyrognostic properties of cookeite are very distinct and serve to identify the mineral readily. When fused it exfoliates very much and colors the flame an intense red from the lithium present. Heated in a closed tube it gives off abundant water. No other known mineral yields these reactions.

Quantitative composition.

The material from the Stewart mine was analyzed, and the results are shown below. No opportunity was had to analyze any other sample, although this would be highly desirable. For comparison three other analyses are added to the table, the original one from Maine by Collier, Penfield's later analysis from Hebron, Maine, and one by Johnston on material from Wait-a-bit Creek, Columbia River, B.C.

Analysis of cookeite from Stewart mine, Pala, with comparative analyses.
 ------ indicates no values detected or not analysed

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[182] Sterrett, D.B., Tourmalines from San Diego, County, California: Am. Jour. Sci., 4th ser., vol. 17, pp. 459-465, 1904

Locality	Pala	Maine	Hebron, Maine	Columbia River, B. C.	Calculated
Analyst-	Schaller	Collier	Penfield	Johnston	
SiO_2	35.53	34.93	34.00	32.00	35.18
Al_2O_3-	44.23	44.91	45.06	45.87	44.71
F_2eO_3	-----	trace	0.45	-----	-----
CaO	Trace	-----	0.04	1.63	-----
MnO	Trace	----------	----------	----------	----------
MgO	----------	----------	--------	0.78	----------
K_2O	--- 0.31	2.57	0.14	0.06	------------
Na_2O	2.11	------	0.19	0.65	--------
Li_2O	2.73	2.82	4.02	2.10	4.36
H_2O	a 14.18	b 13.79	14.96	17.29	15.75
F	1.46	c 0.47	0.46	0.02	-------
Subtotal	100.5	99.49	99.32	100.4	100.00
Excess O	0.61			0.01	
Total	99.94			100.3	

a Including 0.61 percent expelled at 100°
b Including 0.38 per cent expelled at 100°
c Given as SiF_4·

The analyses shown agree closely with the composition calculated from the formula : Li_2O • $3Al_2O_3$ • $4SiO_2$ • $6H_2O$, except that in Collier's analysis some K_2O replaces part of theLi_2O and that in the material from Pala Na_2O replaces part of the Li_2O. Moreover, a little fluorine is present in all the samples analyzed.

Cookeite is derived from elbaite and from spodumene, in the later case apparently without much change in volume. The reactions by which these changes could be represented are probably complex, though the original mineral was doubtless in all cases an aluminum-lithium silicate.

Biotite.

Biotite is present in numerous pegmatite dikes of the region. In most places it is found only in the extreme upper part of the dike, though in a few places it is found scattered through the entire upper portion of the dike. It is a black mica forming very thin scales extending many centimeters across. It alters to chlorite. Mineralogically, it does not present any points of especial interest.

Chlorite.

Chlorite resulting from the alteration of biotite, is found at several places in the pegmatites. On Hiriart Hill, at Pala, it was obtained in some abundance. The material consisted of foliae several centimeters across but without definite crystal outline. The specimens did not indicate any special mineralogical features and were not studied. (All the specimens of this mineral were lost in the fire of 1908.)

Epidote.

Epidote has been noted on Hiriart Hill and at Rincon where it was found with black tourmaline. Its mode of occurrence suggests that of a secondary mineral. The specimens from the pegmatite dikes consists of a radiated mass of greenish prisms not showing any distinct crystal faces.

The mineral has been found at several places in San Diego County, for instance at Bonsall, El Cajon, and Ramona. At these localities it does not occur in the gem tourmaline pegmatites and is, therefore, not in the scope of this report.

Stilbite.

Stilbite is the commonest zeolite found in the pegmatites of the region. It has been collected from the Tourmaline Queen mine (abundant) and from Hiriart Hill (rare), both at Pala; from the Victor mine, at Rincon; and from the Himalaya mine, at Mesa Grande (rare). The mineral may be present at several other localities, for where it occurs as minute isolated crystals (as at Mesa Grande) it may easily evade detection.

The mineral occurs in two forms--as a layer several millimeters thick coating the other minerals of the pegmatite, or as single isolated crystals perched on these minerals. At the Tourmaline Queen mine, at Pala. it was fairly abundant as a layer of well-developed crystals and radiating masses of crystals. This layer coats and incompletely covers green tourmaline, potash feldspar, and albite. The feldspar is fresh and glassy, and the material forming the stilbite was not derived from the minerals on which it is now deposited. The material may, of course, have been derived from neighboring feldspar and may have been deposited as crystals on other feldspars, to which the solution migrated.

The crystals are several millimeters long. Being twinned they have the appearance of orthorhombic symmetry, as is shown in figure 156. A similar form of stilbite is recorded by Rogers[183] for the Victor mine at Rincon.

FIGURE 156.-Stilbite, twinned. Tourmaline Queen mine, Pala. Forms c {001}, b {010}, m {110}, f{1011.

Heulandite.

Rogers[184] describes the heulandite from the Victor mine, at Rincon, as follows: Heulandlte occurs sparingly associated with stilbite. The crystals are pale brown, sharp in angle, and have the usual forms {010}, {001}, {201}, {201}, and {110}. The mineral was not observed in any other mine.

Laumontite.

Laumontite from the Victor mine, at Rincon, was described by Rogers[185] as

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[183] Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego County, California; School of Mines Quart., vol. 31, p. 213, 1910.

[184] Rogers, A F., Minerals from the pegmatite veins of Rincon, San Diego County, California; School of Mines Quart., vol. 31, p. 214, 1910.

[185] Rogers, A F., Minerals from the pegmatite veins of Rincon, San Diego

follows: Minute crystals of the common habit ({110} and (201}) were found on a few specimens as a cavity lining. A very soft radiated white mineral from the Victor Is apparently a laumontite pseudomorph after stilbite.

The mineral was not observed by the writer in association with any of the gem tourmaline pegmatites. It was noted, however, accompanying axinite and epidote in Moosa Canyon near Bonsatt.[186]

Chrysocolla.

Several loose pieces of pegmatite permeated with chrysocolla were found on the top of Hiriart Hill, at Pala. The pegmatite contains considerable biotite and is, therefore, probably from the extreme upper edge of a pegmatite dike. Small masses of an undetermined brown mineral, possibly limonite pseudomorphous after pyrite, are scattered through the rock. The copper of the chrysocolla may then have been derived from a cupriferous pyrite in the pegmatite, though it may also have been derived from a copper-bearing sulphide in the gabbro.

Clays.

The term clay is used to designate the hydrous substances that consist essentially of silica and alumina. Some hold these clays to be definite aluminum silicates; however, others maintain that they are a mixture of silica and alumina gels. They represent substances that have been called halloysite, montmorillonite, cimollite, and so on. They are abundant in nearly all of the exploited deposits, particularly in those at Pala. At the Stewart mine are masses of this clay extending for many feet.

Kaolin or ordinary clay is probably largely derived from the alteration of the potash feldspar in the pegmatite. It is generally stained deep brown by the infiltration of iron compounds, which result from the decomposition of the surrounding iron-rich gabbro. The clay is doubtless in part also derived from the alteration of the feldspar of the gabbro as described on page 000. The other clays, the so-called halloysite, etc., are nearly all pink or red and have been derived from red tourmaline or spodumene. The alteration of elbaite to a clay (halloysite) has been described on page 000, and the alteration of spodumene to a pink clay has been described on page 000. The composition of these pink clays is indicated by the following analyses:

Analyses of pink clays.

[---Leaders indicate not detected. Not determined or analysis was not performed.
W.T. Schaller, analyst.)

County, California; School of Mines Quart., vol. 31, p. 214, 1910.
[186] Schaller, W.T., Axinite from California: U.S. Geol. Survey Bull. 490, p. 37, 1911.

Sample No.	1.	2.	3.	4.	5.	6.
Habit and color-------	Compact, violet	Purple border on muscovite	Compact lithia ore	Violet crystals	Purple crystals	Large crystals
Locality---	40 acres, Pala	Mesa Grande	Stewart mine, Pala	Tourmaline Queen mine, Pala	Tourmaline Queen mine, Pala	Little Three mine, Ramona
SiO_2----------	0.8348	0.8433	0.8499	0.8449	0.8478	0.8534
Al_2O_3-------	.2809	.2620	.2507	.2345	.2221	.2295
Fe_2O_3--------	.0007	.0038	.0007	.0051	.0050	- - -
Mn_2O_3-------	.0036	.0005	.0004	.0082	.0085	- - -
Li_2O----------	.0799	.1428	.1441	.1548	.1712	.2027
Na_2O---------	.0257	.0227	.0313	.0385	.0368	.0337
K_2O----------	.1101	.1094	.1131	.1135	.1125	.1137
H_2O----------	.1750	.0967	.0889	.1061	.1139	.1017
F--------------	.2642	.3531	.3716	.3216	.3358	.4353
SiO_2----------	.8348	.8433	.8499	.8449	.8478	.8534
R_2O_3---------	.2852	.2663	.2518	.2478	.2356	.2295
R_2O----------	.2157	.2749	.2885	.3068	.3205	.3501
F(OH)--------	.6142	.5465	.5494	.5388	.5636	.6387

All these pink clays that have lost the shape of the parent mineral are optically inactive and readily fall to pieces when placed in water. A good deal of the clay resulting from the alteration of kunzite at the Katerina mine, at Pala, is colored a very deep red.